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(54) Title: CASING CONVEYED PERFORATING PROCESS AND APPARATUS

(54) Titre: APPAREIL DE PERFORATION TRANSPORTE AVEC LE TUBAGE, ET PROCEDE CORRESPONDANT

(57) Abstract

A process and apparatus for completing a subterranean well bore in at least one subterranean formation (6). At least one perforating gun assembly (20) is positioned on the outside casing (12) in a subterranean well bore. A suitable signal, such as a hydraulic, electric or wave signal, is transported to the perforating gun assembly so as to detonate one or more explosive charges (30) in the perforating gun assembly (20) which are aimed toward the casing (12). At least one wall in the casing (12) is perforated thereby establishing fluid communication through the wall of the casing (12). Usually, cement (17) surrounding the casing (12) and a subterranean formation (6) surrounding the casing (12) are also perforated to establish fluid communication between the formation and the interior of the casing (12). A logging tool may be positioned exterior to the casing (12). In one embodiment, multiple perforating gun assemblies (20) are located outside the casing (12) and juxtaposed to multiple subterranean formations (6) of interest.

(57) Abrégé

L'invention concerne un procédé et un appareil permettant de réaliser un puits de forage souterrain dans une formation souterraine (6) au moins. A cet effet, on place un ensemble perforateur (20) au moins sur le tubage (12) extérieur dans un puits de forage souterrain. On envoie un signal approprié, tel qu'un signal hydraulique, électrique ou une onde, à l'ensemble perforateur afin de faire exploser une ou plusieurs charges (30) explosives dans l'ensemble perforateur, lesquelles charges sont dirigées contre le tubage (12). On perce ainsi au moins une paroi du tubage (12), ce qui permet d'établir une communication fluide à travers la paroi du tubage (12). De façon générale, on perce également le béton (17) entourant le tubage (12) et une formation souterraine (6) entourant le tubage (12) de manière à établir une communication fluide entre la formation et l'intérieur du tubage (12). Un appareil de diagraphie peut être disposé à l'extérieur du tubage (12). Selon un mode de réalisation, on dispose plusieurs ensembles perforateurs (20) à l'extérieur du tubage (12) et on les juxtapose aux diverses formations souterraines (6) à étudier.

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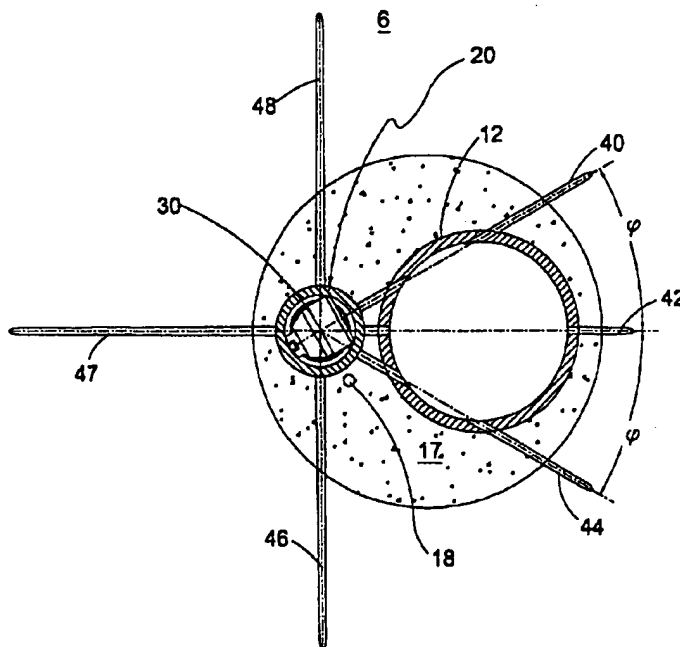
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(54) Title: CASING CONVEYED PERFORATING PROCESS AND APPARATUS

(57) Abstract

A process and apparatus for completing a subterranean well bore in at least one subterranean formation (6). At least one perforating gun assembly (20) is positioned on the outside casing (12) in a subterranean well bore. A suitable signal, such as a hydraulic, electric or wave signal, is transported to the perforating gun assembly so as to detonate one or more explosive charges (30) in the perforating gun assembly (20) which are aimed toward the casing (12). At least one wall in the casing (12) is perforated thereby establishing fluid communication through the wall of the casing (12). Usually, cement (17) surrounding the casing (12) and a subterranean formation (6) surrounding the casing (12) are also perforated to establish fluid communication between the formation and the interior of the casing (12). A logging tool may be positioned exterior to the casing (12). In one embodiment, multiple perforating gun assemblies (20) are located outside the casing (12) and juxtaposed to multiple subterranean formations (6) of interest.



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Description

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CASING CONVEYED PERFORATING PROCESS AND APPARATUS**BACKGROUND OF THE INVENTION****5 FIELD OF THE INVENTION:**

The present invention relates to apparatus and processes for establishing communication through the wall of a well bore tubular, and more particularly, to apparatus and processes for completing a subterranean well, especially to complete a well in and stimulate multiple subterranean zone(s) and/or formations.

DESCRIPTION OF RELATED ART:

Once a subterranean well bore has been drilled by conventional techniques utilizing a drilling string which has a drill bit secured to one end thereof, the well bore is completed by positioning a casing string within the well bore to increase the integrity thereof and provide a path for producing fluids to the surface. The casing string is normally made up of individual lengths of relatively large diameter metal tubulars which are secured together by any suitable means, for example screw threads or welds. Conventionally, the casing string is cemented to the well bore face by circulating cement into the annulus which is defined between the casing string and the well bore. The cemented casing string is subsequently perforated to establish fluid communication between the subterranean formation and the interior of the casing string. Perforating is conventionally performed by means of a perforating gun which has at least one shaped charge positioned within a carrier, the firing of which is controlled from the surface of the earth. A perforating gun may be constructed to be of any length, although a gun to be conveyed on wireline is usually 30 feet or less in length. The perforating gun is lowered within the casing on wireline or tubing to a point adjacent the subterranean zone of interest and the shaped explosive charge(s) are detonated which in turn penetrate or perforate the casing and the formation. In this manner, fluid communication is established between the cased well bore and the subterranean zone(s) of interest. The resulting perforations extend through the casing and cement a short distance into the

5 formation. The perforating gun is then removed from the well bore or dropped
to the bottom thereof. The formation is often stimulated to enhance production
of hydrocarbons therefrom by pumping fluid under pressure into the well and into
10 the formation to induce hydraulic fracturing of the formation or by pumping fluid
5 into the well and formation to treat or stimulate the formation. Thereafter, fluid
may be produced from the formation through the casing string to the surface of
the earth or injected from the surface through the casing string into the
15 subterranean formation.

In some formations, it is desirable to conduct the perforating operations
10 with the pressure in the well overbalanced with respect to the formation
pressure. Under overbalanced conditions, the well pressure exceeds the
20 pressure at which the formation will fracture, and hydraulic fracturing occurs in
the vicinity of the perforations. The perforations may penetrate several inches
into the formation, and the fracture network may extend several feet into the
25 formation. Thus, an enlarged conduit can be created for fluid flow between the
15 formation and the well, and well productivity may be significantly increased by
deliberately inducing fractures at the perforations.

30 Frequently, a subterranean well penetrates multiple zones of the same
subterranean formation and/or a plurality of formations of interest, which are
20 hydrocarbon bearing. It is usually desirable to establish communication with
each zone and/or formation of interest for injection and/or production of fluids.
35 Conventionally, this is accomplished in any one of several ways. First, a single
perforating gun may be conveyed on wireline or tubing into the subterranean well
bore and fired to perforate a zone and/or formation of interest. This procedure
40 is repeated for each zone to be treated. Alternately, a single perforating gun is
25 conveyed on wireline or tubing into the subterranean well and the gun is
positioned adjacent to each zone and/or formation of interest and selectively
45 fired to perforate each zone and/or formation. In accordance with another
approach, two or more perforating guns are positioned in a spaced apart manner
30 on the same tubing, are conveyed into the well and fired. When the select firing
method is used and the subterranean zone(s) and/or formation(s) of interest are

5 relatively thin, e.g. 15 feet or less, the perforating gun is positioned adjacent the
zone of interest and some of the shaped charges of the perforating gun are fired
to selectively perforate only this zone or formation. The gun is then repositioned
by means of the wireline to another zone or formation and certain shaped
10 5 charges are fired to selectively perforate this zone or formation. This procedure
is repeated until all zone(s) and/or formation(s) are perforated and the
perforating gun is retrieved to the surface by means of the wireline. In the tubing
conveyed, spaced gun approach, two or more perforating guns are conveyed
15 into the well bore on the same tubing in a spaced apart manner such that each
gun is positioned adjacent one of the subterranean zone(s) and/or formation(s)
20 of interest. Once positioned in the well, the guns may be simultaneously or
selectively fired to perforate the casing and establish communication with each
such zone(s) and/or formation(s).

If the zone(s) and/or formation(s) which have been perforated by either
25 15 conventional approach are to be hydraulically fractured, fluid is pumped into the
well under pressure which exceeds the pressure at which the zone(s) and/or
formation(s) will fracture. However, the fracturing fluid will preferential flow into
those zone(s) and/or formation(s) which typically have the greatest porosity
30 and/or the lowest pressure thereby often resulting in little or no fracturing of
some of the zone(s) and/or formation(s). Further, considerable expense can be
20 incurred in pumping fluid under sufficient pressure to fracture multiple zone(s)
and/or formation(s) penetrated by a subterranean well bore. In an effort to
rectify this problem, a procedure has been utilized wherein a perforating gun is
35 lowered into a well on tubing or wireline adjacent the lowermost zone of interest
and fired to perforate the casing and zone. Thereafter, the it is necessary to trip
40 25 out of the well and remove the perforating gun to the surface. Fluid is then
pumped into the well at sufficient pressure to fracture or stimulate the lowermost
zone. The stimulation fluid may be recovered from the zone just perforated and
fractured to inhibit any damage to the zone which may occur as a result of
45 30 prolonged contact with the fracturing fluid. Prior to perforating and stimulating
the next deepest zone of interest, a mechanical device or plug or sand fill is set
in the well between the zone just fractured and the zone to be fractured to isolate

5 the stimulated zone from further contact with fracturing fluid. This procedure is repeated until all zone(s) and/or formation(s) are perforated and fractured. Once this completion operation is finished, each plug must be drilled out of or otherwise remove the well to permit fluid to be produced to the surface through
10 the well. However, the necessity of tripping in and out of the well bore to perforate and stimulate each of multiple zone(s) and/or formation(s) and the use of such plugs to isolate previously treated zone(s) and/or formation(s) from further treatment fluid contact is time consuming and expensive. In view of this, multiple zone(s) and/or formation(s) are often stimulated at the same time even
15 though this results in unacceptable of treatment of certain zone(s) and/or formation(s). Thus, a need exists for apparatus and processes to perforate casing which is positioned within a subterranean well bore which eliminates the need to run perforating equipment in and out of the well when completing multiple zone(s) and/or formation(s).

20 Accordingly, it is an object of the present invention to provide a method and apparatus for economically and effectively perforating and stimulating multiple subterranean zone(s) and/or formation(s) which are penetrated by a subterranean well.

25 It is another object of the present invention to provide a process and apparatus for completing a subterranean well wherein casing is perforated to provide for fluid communication across the wall of the casing by means of a perforating gun assembly located in a subterranean well bore outside the casing.

30 It is a further object of the present invention to provide a process and apparatus wherein for completing and stimulating a cased, subterranean well bore wherein entry into the well bore to effectuate completion and/or stimulation is obviated.

35 It is still another object of the present invention to provide a process and apparatus for expeditiously treating and/or stimulating each subterranean formation penetrated by a subterranean well bore individually and therefore economically.

40 It is a still further object of the present invention to provide a process and apparatus for completing a subterranean well wherein multiple perforating gun

5 assemblies are positioned in the well bore external to casing and adjacent to multiple subterranean formations of interest and selectively detonated to establish fluid communication between a subterranean formation and the interior of the casing.

10 5

SUMMARY OF THE INVENTION

15 To achieve the foregoing and other objects, and in accordance with the purposes of the present invention, as embodied and broadly described herein, one characterization of the present invention may comprise a process for establishing fluid communication. The process comprises positioning at least one explosive charge in a subterranean well bore such that the at least one explosive charge is placed external to casing which is also positioned within the well bore and is aimed toward the casing and detonating the at least one explosive charge so as to perforate the wall of the casing at least once.

20 25 15 In another characterization of the present invention, a process is provided for completing a subterranean well bore which comprises penetrating the wall of a casing which is positioned and cemented within a subterranean well bore from the exterior of the casing to the interior.

30 20 In yet another characterization of the present invention, a process is provided for completing a subterranean well which comprises positioning at least one explosive charge in a subterranean well bore outside of casing and detonating the at least one explosive charge so as to perforate the casing.

35 40 25 In yet another characterization of the present invention, a process is set forth for providing fluid communication across the wall of a casing. The process comprises detonating a first perforating gun assembly which is positioned outside of a casing in a subterranean well bore thereby perforating the casing.

45 30 In a further characterization of the present invention, a process is provided for completing one or more subterranean formations. The process comprises detonating a first perforating gun assembly which is positioned outside of a casing in a subterranean well bore thereby perforating the casing and a first subterranean formation.

5 In a still further characterization of the present invention, a process is provided for completing a subterranean well which comprises penetrating casing which is positioned in a subterranean well bore while the interior of the casing remains unoccupied by perforating guns or other equipment, tools, tubulars or
10 lines.

In a still further characterization of the present invention, a subterranean completion system is provided which comprises a casing which is at least partially positioned within a subterranean well bore and at least one perforating gun assembly which is positioned external to the casing and within the well bore.
15 The perforating gun assembly has at least one explosive charge aimed in the direction of the casing.

20 In a still further characterization of the present invention, a completion system is provided which comprises a casing and at least one perforating gun which is connected to the exterior of the casing and has at least one explosive
25 charge aimed toward the casing.

BRIEF DESCRIPTION OF THE DRAWINGS

30 The accompanying drawings, which are incorporated in and form a part of the specification, illustrate the embodiments of the present invention and, together with the description, serve to explain the principles of the invention.

In the drawings:

35 FIG. 1 is a sectional view of the assembly of the present invention as positioned within a subterranean well bore;

40 FIG. 2 is a cross sectional view of the assembly of the present invention as positioned within a subterranean well bore taken along the line 2-2 of FIG. 1;

FIG. 3 is a cross sectional view of the assembly of the present invention as positioned within a subterranean well bore taken along the line 2-2 of FIG. 1 after at least one explosive charge of a perforating gun has been detonated;

45 FIG. 4 is a cross sectional view of the assembly of the present invention as positioned and cemented within a subterranean well bore;

5 FIG. 5 is a cross sectional view of the assembly of the present invention as positioned and cemented within a subterranean well bore taken along the line 5-5 of FIG. 4;

10 FIG. 6 is a cross sectional view of the assembly of the present invention
5 as positioned and cemented within a subterranean well bore taken along the line 5-5 of FIG. 4 after at least one explosive charge of a perforating gun has been detonated;

15 FIG. 7 is a partially cut away, perspective view of the assembly of the present invention, including a perforating gun assembly having multiple explosive
10 charges, as detonated;

20 FIG. 8 is a top view of the assembly of the present invention depicted in FIG. 7 as positioned and cemented within a subterranean well bore and detonated, which illustrates one embodiment of charge phasing;

25 FIG. 9 is a partially cut away, partially sectional view of the assembly of
15 the present invention, including a perforating gun assembly having multiple explosive charges, as positioned and cemented in a subterranean well bore;

30 FIGS. 10a-g are partially cut away, schematic views of one embodiment of the present invention wherein multiple subterranean formations are stimulated and/or treated;

20 FIGS. 11a-f are partially cut away, schematic views of another embodiment of the present invention which is utilized to stimulate and/or treat
35 multiple subterranean formations wherein a zone isolation device is positioned between perforating gun assemblies;

40 FIGS. 12a, 13a, 14a, 15a and 16a are partial cross sectional views which,
25 as combined in the sequence noted, illustrate another embodiment of the present invention which is utilized to stimulate and/or treat multiple subterranean formations wherein flapper valve sub-assemblies are positioned between perforating gun assemblies;

45 FIGS. 12b, 13b, 14b, 15b and 16b are partial cross sectional views which,
30 as combined in the sequence noted, illustrate another embodiment of the present invention which is utilized to stimulate and/or treat multiple subterranean formations wherein flapper valve sub-assemblies are positioned between
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5 perforating gun assemblies and wherein one of the perforating gun assemblies has been detonated;

10 FIGS. 12c, 13c, 14c, 15c and 16c are partial cross sectional views which, as combined in the sequence noted, illustrate another embodiment of the present invention which is utilized to stimulate and/or treat multiple subterranean formations wherein flapper valve sub-assemblies are positioned between perforating gun assemblies and wherein both of the perforating gun assemblies have been detonated;

15 FIG. 17 is a sectional view of a specialty collar utilized in the embodiment of the present invention which is illustrated FIGS. 12a - 16a as assembled;

20 FIG. 18 is a sectional view of a portion of one of the perforating gun assemblies which is illustrated in FIGS. 12a and 12b; and

FIG. 19 is a sectional view of a portion of one of the perforating gun assemblies which is illustrated in FIG. 12c.

25 15 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

30 In accordance with the present invention, an assembly is provided for positioning within a subterranean well bore during completion thereof. The assembly comprises one or more perforating guns which are positioned adjacent the exterior of casing such that at least one explosive charge of the perforating gun is oriented to strike the casing. As utilized throughout this disclosure, the term "casing" refers to the tubulars, usually a string made up of individual joints of steel pipe, used in a well bore to seal off fluids from the well bore, to keep the walls of the well bore from sloughing off or caving in and through which fluids are produced from and/or injected into a subterranean formation or zone. The term 40 25 "perforating gun" refers to an assembly for positioning in a subterranean well bore which contains one or more explosive charges which are ballistically connected to the surface and which are designed to penetrate the wall of casing.

45 Referring to FIG. 1, a subterranean well bore 2 is illustrated as extending from the surface of the earth or sea floor 4 and penetrating at least one subterranean formation 6. "Subterranean formation" as utilized throughout this disclosure refers to a subterranean formation, a layer of a subterranean formation and/or a zone of a layer of a subterranean formation which represents 50

5 a given stratigraphic unit, such as a unit of porosity, permeability and/or hydrocarbon saturation. The assembly of the present invention is illustrated generally as 10 in FIG. 1 and comprises a perforating gun assembly 20 and casing 12. As assembled and positioned within well bore 2, the perforating gun assembly is positioned on the exterior of casing 12 adjacent the outer diameter thereof. Preferably, the perforating gun assembly 20 is secured to casing 12 by any suitable means, for example by metal bands, such as stainless steel bands, wrapped around both casing 12 and perforating gun assembly 20 or with specialty connections, to ensure that the relative position between perforating gun assembly 20 and casing 12, as fully assembled does not substantially change, either axially or rotationally, during positioning of the assembly of the present invention in well bore 2. The assembly of the present invention is preferably constructed either before and/or at the well site, i.e. either onshore location or offshore platform, at the surface 4 prior to running the assembly into well bore 2. As illustrated in FIG. 1, a control system 18, for example an electric line, extends from a suitable power source (not illustrated) at the surface 4 as will be evident to a skilled artisan to the perforating gun assembly 20 to provide an appropriate signal to ignite the perforating gun assembly. Where electric line is utilized, it is preferred that the line is armored for protection against damage during placement of the assembly in the well bore and that the line be secured to the casing by any suitable means, such as those described above with respect to securing the perforating gun assemblies. Other suitable control systems for igniting the explosive charge(s) contained in perforating gun assembly 20, such as hydraulic lines connected to a suitable source of pressurized hydraulic fluid (liquid or gas) or electromagnetic or acoustic signaling and corresponding receivers (not illustrated) connected to the perforating gun assemblies for wave transmissions through the casing, soil and/or well bore fluids, may also be employed in the present invention. Any line or any other instrument mentioned below in conjunction with the assembly of the present invention should be secured to the casing at appropriate intervals to inhibit damage during positioning of the assembly in the well bore.

5 Perforating gun assembly 20 has at least one explosive charge 22
contained therein which is aimed toward casing 12. As illustrated in FIG. 2,
assembly 20 has two explosive charges 22, 26 which are axially spaced apart
within assembly 20 and which, although oriented at slightly different angles, are
10 5 both aimed toward casing 12. Upon transmission of a suitable signal, for
example, electrical current via line 18, explosive charge 22 detonates and fires
a shaped charge along path 24 creating perforations 13 and 14 in the wall of
casing 12 while explosive charge 26 detonates and fires a shaped charge along
15 path 28 creating perforations 15 and 16 in the wall of casing 12. It should be
noted that although each charge is illustrated as being capable of creating two
perforations in the wall of casing 12, these charges may be constructed so as
20 just to punch a single perforation, for example 13 and 15, through the wall of
casing 12 where desirable. For example, the assembly of the present invention
may be employed wherever it is desirable to create fluid communication across
25 15 the wall of casing, such as to monitor conditions within the interior of the well
bore or to actuate a tool which is positioned on the outside of casing 12.

 In one embodiment as illustrated in FIG. 4, the assembly of the present
invention is positioned within a subterranean well bore after the well bore is
30 drilled but prior to completing the well. Preferably, the assembly is positioned
adjacent a subterranean formation of interest by any suitable means. The
20 position of subterranean formation 6 will be known from open hole logs, such as
gamma ray logs, which are run during or after a well bore is drilled and to a
35 lesser extent by certain indications obtained during drilling, such as mud logs
and/or changes in drilling penetration rates. As the assembly is being positioned
25 within the well bore, a log may be obtained by extending a logging tool, such as
a gamma ray tool, through casing 12 so as to align perforating assembly 20 with
40 formation 6, or alternatively, by securing a logging tool 50 on the outside of
casing 12 and adjacent the perforating gun assembly to obtain real time logs. By
45 correlating these logs with open hole logs, the perforating gun assembly may be
30 accurately positioned adjacent the subterranean formation 6 of interest. Often
it is desirable to circulate fluid through the casing and the annulus defined
between the casing and the well bore prior to cementing. As will be evident to

5 a skilled artisan, the temperature of such fluid and of the cement during setting
may cause the casing to contract or expand and such change should be taken
into consideration during the initial placement of the assembly of the present
10 invention in the well bore, especially where the formation of interest is relatively
5 thin or short in length. Once the perforating gun assembly is properly positioned
within the well bore, cement 17 is circulated either down through the interior 13
of casing 12 and back towards the surface via the annulus 19 formed between
15 the casing and the well bore or, less preferably, down annulus 19 towards the
bottom of the well bore. Prior to cement 17 being fully cured, casing 12 may be
10 axially reciprocated to ensure that the cement is uniformly positioned about
casing 12.

20 In the manner just described, the assembly of the present invention is
cemented in the well bore (FIG. 4) between the casing and the face of the well
bore and is capable of being remotely actuated by any suitable means 18, such
25 as electric line, hydraulic line, radio signals, etc. at a later time. Perforating gun
15 assembly 20 has at least one explosive charge 22 contained therein which is
aimed toward casing 12. As illustrated in FIG. 5, assembly 20 has two explosive
charges 22, 26 which are axially spaced apart and which, although oriented at
30 slightly different angles, are both aimed toward casing 12. Upon transmission
20 of a suitable signal via means 18, for example electric current via an electric line,
explosive charges 22 and 26 detonate. Upon detonation, explosive charge 22
fires a shaped charge along a path 24 thereby creating perforations 13 and 14
35 in the wall of casing 12 and a perforating tunnel 32 which extends through
cement 17 and into subterranean formation 6, while explosive charge 26 fires a
25 shaped charge along path 28 thereby creating perforations 15 and 16 in the wall
of casing 12 and a perforating tunnel 34 which extends through cement 17 and
40 into the subterranean formation 6. In this manner, fluid communication is
established between formation 6 and the interior of casing 10. It should be
45 noted that although each charge is illustrated as being capable of creating two
30 perforations in the wall of casing 12, these charges may be constructed so as
just to punch a single perforation, for example 13 and 15, through the wall of
casing 12 where desirable. For example, it may be desirable to establish fluid

5 communication between a separate tool (not illustrated), such as pressure gauge, which is located on the exterior of the casing adjacent and in fluid communication with the perforating assembly.

10 Thus, the process or method of the present invention broadly entails
5 positioning a perforating gun assembly in a subterranean well bore outside of and juxtaposed to casing and detonating at least one explosive charge in the perforating gun assembly to penetrate the casing wall at least once. Preferably,
15 the assembly of the present invention is cemented in the subterranean well bore and detonation of the explosive charge creates a perforation tunnel through the
10 cement and into the subterranean formation. Even though each perforating gun assembly 20 may contain a multitude of explosive charges 30 as will be evident to a skilled artisan, it is only necessary to aim one such charge at casing 12 to practice the present invention. However, as a perforating gun assembly conventionally contains several explosive charges per foot, e.g. 6 (FIG. 7), it is
20 usually desirable to have several charges in a given assembly aimed at the casing as run in a well bore. A preferred phasing pattern for six explosive charges in an assembly having at least six explosive charges is illustrated in FIG. 8. In this embodiment, the six charges 30 are axially and radially spaced in perforating gun assembly 20 in a spiral pattern. Three of the six charges are
25 oriented to perforate casing 12 and create perforating tunnels 40, 42 and 44 upon detonation which extend through cement 17 into formation 6 while the remaining three charges are oriented so as to create perforating tunnels 46, 47 and 48 upon detonation penetrate the cement 17 and formation 6 but not casing 12. As illustrated in FIG. 8, the angle α between tunnels 40 and 42 and between
30 tunnels 42 and 44 is substantially equal and will depend upon the diameter of the casing and perforating gun assembly and the spacing between the casing and assembly. For example, the angle α for a 2 1/8" perforating gun assembly and 4 1/2" casing is 30°, for a 2 3/8" assembly and 3 1/2" tubing is 22.5° and for a 2 7/8 " assembly and 2 7/8" casing is 17.5°. Perforating tunnels 40, 42, 44 and
35 46-48 are formed by firing the explosive charges in sequence beginning from either end of the gun. Further, although it is preferred that the explosive charges of each assembly are oriented to shoot in a plane which is perpendicular to the

5 axis of the assembly, one or more charges may be arranged to be shot at an angle with respect to the horizontal plane.

10 In a further embodiment of the present invention, the assembly of the present invention is constructed of casing 112 and multiple perforating gun
5 assemblies 120a-e (FIG. 9). As assembled and positioned within well bore 102, the perforating gun assemblies are positioned on the exterior of casing 112 adjacent the outer diameter thereof. It is preferred that the perforating gun
15 assemblies 120a-e be secured to casing 112 by any suitable means, for example by metal bands wrapped around both casing 112 and perforating gun
10 assemblies 120a-e or a specialty connector, to ensure that the relative position between each perforating gun assembly 120 and casing 112 as fully assembled does not substantially change during positioning of the assembly of the present
20 invention in well bore 102. Each perforating gun assembly has at least one explosive charge which is aimed so as to perforate the casing upon detonation thereof. The assembly of the present invention is preferably fully constructed at
25 the well site, i.e. either onshore well head or offshore platform, at the surface 104 prior to running the assembly into well bore 102. As illustrated in FIG. 9, a signal means 118, for example an electric line, extends from a suitable power
30 source (not illustrated) at the surface 104 to the perforating gun assemblies 120a-e to provide a power source for ignition.

35 Multiple perforating gun assemblies 120a-e are positioned within a subterranean well bore 102 adjacent multiple subterranean formations of interest 106a-e after the well bore is drilled but prior to completing the well. The
40 assembly is positioned adjacent a subterranean formation of interest by any suitable means. The position of subterranean formations 106a-e will be known from open hole logs and drilling data as previously discussed. As the assembly
45 is being positioned within the well bore, a cased hole log may be obtained and correlated with open hole logs to accurately position perforating gun assemblies 120a-e adjacent the subterranean formations 106a-e of interest. Often it is
30 desirable to circulate fluid through the casing and the annulus defined between the casing and the well bore prior to cementing. As will be evident to a skilled artisan, the temperature of such fluid and of the cement during setting may

5 cause the casing to contract or expand and such change should be taken into
consideration during the initial placement of the assembly of the present
invention in the well bore, especially where the formation of interest is relatively
10 thin. Once the perforating gun assemblies are properly positioned within the well
5 bore, cement 117 is circulated either down through the interior 113 of casing 112
and back to the surface via the annulus 119 formed between the casing and the
well bore or, alternatively, down annulus 119 and through casing 112 up to the
15 surface. Prior to cement 117 being fully cured, casing 112 may be axially
reciprocated to ensure that the cement is uniformly positioned about casing 112.

10 As thus constructed, the multiple perforating gun assemblies 120a-e which are
positioned adjacent subterranean zones of interest 106a-e may be subsequently
20 detonated simultaneously, sequentially or in any desired order by transmission
of a suitable signal to each perforating gun assembly via electrical, hydraulic,
audio wave or any other suitable means.

25 15 In accordance with one aspect of the embodiment of the present invention
which is illustrated in FIG. 9, perforating gun 120a is fired or detonated upon
receiving a signal via signal means 118 thereby forming perforation(s) 150a
30 (FIG. 10a) through casing 112 and cement 117 into formation 106a in a manner
as previously described with respect to the embodiments illustrated in FIGS. 6-8
20 above. Thereafter, stimulation fluids 160a, such as fracturing fluid containing
proppants and/or acids containing balls which act as diverting agents in the
35 formation, and/or treatment fluids, for example scale inhibitors and/or gelation
solutions, are pumped from surface 104 through the interior 113 of casing 112
and into perforations 150a (FIG. 10b). Radioactive tracers may be incorporated
40 25 into the stimulation and/or treatment fluids to ensure proper placement of fluids
and/or solids contained therein. In the case of fracturing fluids, fractures 156a
are formed and propagated within formation 106a. Where stimulation fluids,
45 such as acidizing fluids, and/or treatment fluids are employed, these fluids need
not be pumped at pressures sufficient to create fractures 156a. As the
30 stimulation and/or treatment process continues, screen out occurs during the
pumping operation when the proppant and/or balls create a significant flow
restriction in the well bore 102. At this point (FIG. 10c), the process may be
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5 suspended, for example where it is desirable to produce fluids from formation
106a for testing and/or evaluation purposes, or the next formation 106b may be
immediately treated in a similar fashion to that just described with respect to
10 formation 106a (FIGS. 10d-f). This process is repeated for each zone to be
5 treated until conclusion (FIG. 10g).

In accordance with another embodiment of the assembly of the present
invention which is illustrated in FIG. 11, zone isolation devices 230a and 230b
15 are secured to casing 212 between perforating gun assemblies 220 a-c. As
illustrated, the zone isolation devices are connected to signal means 218 and
10 preferably are secured to casing 212 by any suitable means, for example by
screw threads or welds. Suitable zone isolation devices, for example flapper
20 valves or ball valves, are employed in the process of the present invention as
hereinafter described to selectively shut off flow through the interior 213 of
casing 212. In operation, perforating gun 220a is fired or detonated upon
25 receiving a signal via signal means 218 thereby forming perforation(s) 250a
(FIG. 11a) through casing 212 and cement 217 into formation 206a in a manner
as previously described with respect to the embodiments illustrated in FIGS. 6-
10 above. Thereafter, stimulation fluids 260a, such as fracturing fluid containing
30 proppants and/or acids, and/or treatment fluids, for example scale inhibitors
and/or gelation solutions, are pumped from surface 204 through the interior 213
20 of casing 212 and into perforations 250a (FIG. 11b). Radioactive tracers may
be incorporated into the stimulation and/or treatment fluids to ensure proper
35 placement of fluids and/or solids contained therein. In the case of fracturing
fluids, fractures 256a are formed and propagated within formation 206a. Where
25 stimulation fluids, such as acidizing fluids, and/or treatment fluids are employed,
these fluids need not be pumped at pressures sufficient to create fractures 256a.
40 When the stimulation and/or treatment process is completed, a signal is sent to
isolation device 230a and perforating gun 220b via signal means 218. In
response, perforating gun 220b is fired or detonated thereby forming
45 perforation(s) 260b (FIG. 11c) while isolation device 230a is activated to seal
30 interior 213 of casing 212 against fluid flow. Detonation of perforating gun 220b
and activation of isolation device 230a may occur substantially simultaneously

5 or sequentially although it is preferred that perforating gun 220b be fired immediately before isolation device 230a is activated. At this point (FIG. 11d), the next formation 206b is immediately treated in a similar fashion to that just described with respect to formation 206a (FIG. 11d). The surface equipment
10 necessary to pump the stimulation and/or treatment fluids through casing 212 need not be moved off the surface well site during operation in accordance with the present invention nor rigged up or down thereby saving costs associated with such operations. This process is repeated for each zone to be treated (FIG. 11e) until conclusion (FIG. 11f). Upon completion, zone isolation devices 230a
15 and 230b may be actuated into an open position or destructed by any suitable means, such as drilling, to permit flow through the interior 213 of casing 212 for fluids produced from and/or injected into formations 206a, 206b and/or 206c. Although illustrated in FIGS. 11a-11f as being applied to three formations, the process illustrated for this embodiment of the present invention may be applied
20 to any number of subterranean formations which are penetrated by a subterranean well bore.

An embodiment of the assembly and process of the present invention which utilizes zone isolation devices between perforating gun assemblies is illustrated generally as 300 in FIGS. 12a - 16a and comprises at least two
30 perforating gun assemblies 320 and 320a which are secured to the outside of casing 310 which is made up of individual lengths of pipe in a manner as described below and a flapper valve assembly 380 which is positioned between perforating gun assemblies 320, 320a as described below. A first length of casing 310, a first speciality collar 304, a first male to female connector 314, a
35 flapper valve sub-assembly 380, a second length of casing 310, a collar 316, a third length of casing 310 and a second speciality collar 312 are secured together in the sequence as just described and illustrated in FIG. 12 by any suitable means, such as screws threads. As illustrated in FIGS. 12 and 13, each speciality collar 304 has a first generally cylindrical shaped, axially extending bore
40 305 therethrough having screw threaded ends and a second smaller diameter axially extending bore 306 which is axially offset from bore 305 and having an enlarged end 307 which is provided with screw threads for engagement with a

5 perforating gun assembly and a second end which is threaded for engagement with a hydraulic line as hereinafter described.

10 Flapper valve subassembly 280 comprises generally tubular body sections 381, 383, 385 and 386 which are secured together by any suitable means, such as by screw threads. O-ring seals 382, 388 and 387 provide a fluid
15 tight connection between these generally tubular body sections. Body section 383 is provided with a port 389 which provides for fluid communication through the wall of section 383 and is threaded on one end for attachment to a hydraulic line as hereinafter described. A sleeve 400 is received within body sections 381,
20 383, 385 and 386 such that, when assembled in the positioned illustrated in FIGS. 14a and 15a, two annular chambers 394 and 395 are defined therebetween. Sleeve 400 has a raised outer portion 402 intermediate the length thereof thereby defining opposing generally annular shoulders 404 and 406. Sleeve 400 may move with respect to the body sections with the amount
25 of movement being limited by raised outer portion 402 abutting the ends of annular chamber 395. Annular seal rings 392 and 393 provide a fluid tight seal between sleeve 400 and body sections 381 and 383. A flapper valve 396 is rotatably secured to body portion 386 and is biased toward a closed position in engagement with generally annular seat 399 formed by one end of body portion
30 386 by means of spring 398 so as to block fluid flow through the interior bore 390 of the sub-assembly. As assembled, flapper valve 396 is positioned in an open, retracted position within annular chamber 394 and held therein by sleeve 400. Sleeve 400 is held in this position by means of ambient air pressure in chamber 395 acting against shoulder 404. Flapper valve 396 is constructed of any
35 suitable material, for example ceramic or relatively soft metal such as aluminum or cast iron, which may be removed by rotary drilling or percussive means.

40 Perforating gun assemblies 320 and 320a each comprise a detonating assembly 330 and a perforating gun 350. Any suitable detonating assembly known to those skilled in the art may be used. An example of a detonating
45 assembly suitable for use with the casing conveyed perforating assembly of the present invention is shown in FIGS. 13a and 16a. One end of an outer generally cylindrical housing 331 is secured to enlarged end 307 of specialty collar 304
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5 while the other end is secured to a second sub 332 which in turn is secured to
a third sub 333 by any suitable means, such as by screw threads. In addition,
the outer housing 331 of perforating gun assembly 320a has a outwardly
10 extending spigot 364 which contains a bore 365 in fluid communication with in
5 interior of outer housing 331 as hereinafter described in greater detail. Vent
housing 334 which has a vent 335 formed intermediate the length thereof has
one end thereof secured to internal sub 346 which in turn is secured to second
15 sub 332. A piston 336 is received within vent housing 334 and tubular end cap
337 and is initially held in place by means of shear pins 338 mounted in shear
10 set 339. Piston 336 is elongated and is connected to pin 315 in assembly 320a.
20 A firing pin 340 extends from one end of the bottom of piston 336. An annular
chamber 341 defined between piston 336 and firing head 342 is filled with air at
atmospheric pressure. Firing head 342 abuts a shoulder in the interior wall of
25 vent housing 334 in the detonator assembly as fully constructed and functions
15 to retain percussion detonator 343 against an ignition transfer 345 in one end of
internal sub 346. Internal sub 346 is secured to second sub 334 by any means,
such as screw threads. Each of ignition transfer 345, internal sub 346, second
30 sub 332 and third sub 334 are provided with an internal bore through which
detonating cord 349 passes. Booster transfers 347, 348 are located in second
20 and third subs 332, 334, respectively, linking segments of the detonating cord
349 above and below the junction between second and third subs 332, 334.
35 One end of third sub is secured to one end of a perforating charge carrier 352
of perforating gun assembly 350 while the other end of charge carrier 352 is
secured to bull plug 353 by any suitable means, such as screw threads. Charge
40 carrier 352 may be a commercially available carrier for perforating charges and
25 contains at least one conventional perforating charge 356 capable of creating an
aperture in casing and a portion of the adjacent subterranean formation. A
45 perforating charge tube 354 is positioned within carrier 352 and has at least one
relatively large aperture or opening 355 therein which may be spaced both
30 vertically along and angularly about the axis of the tube. Charge carrier 352 and
perforating charge tube 354 have generally elongated tubular configurations. A
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5 lined perforating charge 356 is secured in an aperture or opening 355 in
perforating charge tube 354 in a manner as will be evident to a skilled artisan,
such that the large end 357 thereof is aligned with and protrudes through
10 opening or aperture 355 in tube 354. If multiple charges are present, they may
5 be spaced vertically along and angularly about the axis of the carrier. The
charge density is an appropriate density determined by methods known to those
skilled in the art. Common charge densities range between two and twenty four
15 per foot. Detonating cord 349 is connected to the small end 358 of each
perforating charge 356 and to end cap 359 in bull plug 353.

10 As illustrated in FIGS. 13a and 14a, perforating gun assembly 320a is
provided with a sub 322 in lieu of a bull plug. Sub 322 has a bore 323
20 therethrough and is secured at the other end to piston housing 324 which
slidingly receives a piston 326 in the interior 325 thereof. The other end of piston
housing is connected to a plug 327 having a bore 328 therethrough which has
25 one end thereof threaded for connection to a hydraulic line.

As assembled and illustrated in FIGS. 12a-16a, a first hydraulic line 402
30 extends to a suitable source (not illustrated) of hydraulic fluid under pressure at
the surface as will be evident to a skilled artisan and is secured within one end
of bore 306 through specialty connector 304 by any suitable means, such as by
20 a threaded ferule 403. Another hydraulic line 404 has one end thereof connected
to connected to bore 365 in spigot 364 of perforating gun assembly 320a while
35 the other end thereof is connected to one end of bore 306 through specialty
connector 304 by any suitable means, such as by a threaded ferules 405 and
406, respectively. Still another hydraulic line 407 has one end thereof connected
40 to connected to one end of bore 328 in plug 327 of perforating gun assembly
320a while the other end thereof is connected to the threaded end of port 389
25 in body section 383 of flapper valve subassembly 380 by any suitable means,
such as by a threaded ferules 408 and 409, respectively.

45 In operation, the embodiment of the assembly of the present illustrated
30 in FIGS. 12a - 16a is positioned in a subterranean well bore such that perforating
gun assemblies are adjacent subterranean formations of interest 206a and 206b
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(FIG. 11a). Hydraulic fluid is then transported under pressure from a suitable source via hydraulic line 402 to the internal bore through perforating gun assembly 320a where, as illustrated in greater detail in FIG. 18, the hydraulic fluid is diverted through bore 365 in spigot 364 and into hydraulic line 404 and perforating gun assembly 320 where the pressure exerted by the hydraulic fluid causes shear pins 338 to shear and firing pin 340 to strike firing head 342 and igniting percussion detonator 343. The ignition of percussion detonator 343 causes a secondary detonation in ignition transfer 345, which in turn ignites detonating cord 349. Detonating cord 349 comprises an explosive and runs between the ends of each charge carrier, passing between the backs of the charges and the charge clips holding the charges in the carrier. Cord 349 ignites the charges 356 in charge carrier 352 and booster transfers, which contains a higher grade explosive than detonating cord 349. Detonation of charges 356 in perforating gun assembly 320 forms perforation(s) 250a through casing 212 (FIG. 16b), i.e. perforations 311 through casing 310 (FIGS. 16b and 16c), and cement 217 into formation 206a in a manner as previously described with respect to the embodiments illustrated in FIG. 11a above. Thereafter, stimulation fluids 260a, such as fracturing fluid containing proppants and/or acids, and/or treatment fluids, for example scale inhibitors and/or gelation solutions, are pumped from surface 204 through the interior 213 of casing 212 and into perforations 250a (FIG. 11b). Radioactive tracers may be incorporated into the stimulation and/or treatment fluids to ensure proper placement of fluids and/or solids contained therein. In the case of fracturing fluids, fractures 256a are formed and propagated within formation 206a. Where stimulation fluids, such as acidizing fluids, and/or treatment fluids are employed, these fluids need not be pumped at pressures sufficient to create fractures 256a.

When the stimulation and/or treatment process is completed, hydraulic pressure is increased in line 402 until shear pins 338 in perforating gun assembly 320a shear. At this point, piston 336 in perforating gun assembly is free to move which caused pin 315 to contact causing sleeve 317 in perforating gun assembly 320a to shift (FIG. 19) thereby sealing bore 365 in spigot 364

5 against fluid flow. Movement of piston 336 also causes firing pin 340 to strike
firing head 342 thereby igniting percussion detonator 343, detonating cord 349
and charges 356 (FIG. 13c) in charge carrier 352 forming perforation(s) 260b
10 (FIG. 11c), i.e. perforations 313 through casing 310 (FIG. 13c). The pressure
5 from fluid in the interior of casing 310 is communicated to the interior 325 of
housing 324 thereby forcing piston 326 in assembly 320a to flow hydraulic fluid
to flow through line 407, port 389 and act against shoulder 406 of sleeve 400.
15 In response, sleeve 400 moves until shoulder 404 abuts the end of chamber 395
thereby permitting flapper valve 396 to rotate into engagement with seat 399
20 (FIG. 15c). In this manner, flapper valve 380 seals the interior of casing 310
(212 in FIG. 11b) against fluid flow. Thereafter, stimulation fluids 260b, such as
fracturing fluid containing proppants and/or acids, and/or treatment fluids, for
example scale inhibitors and/or gelation solutions, are pumped from surface 204
through the interior 213 of casing 212 (310) and into perforations 250b (FIG.
25 11d), i.e. perforations 313 (FIG. 13c). Upon completion, zone isolation devices
230a and 230b may be actuated into an open position or destructed by any
suitable means, such as drilling, to permit flow through the interior 213 of casing
212 for fluids produced from and/or injected into formations 206a, 206b and/or
30 206c.

20 While the embodiment of the assembly of the present invention which is
illustrated in FIG. 12a-16a as having two perforating assemblies 320 and 320a
for completion of two subterranean formations, it will be evident to a skilled
artisan that the assembly of this embodiment may be applied to three or more
subterranean formations by repeating the portion of assembly 300 denoted as
25 301 in FIGS. 12A-16A. Proper spacing between perforating gun assemblies 320
and 320a or repetitive assemblies 320a for treatment of multiple subterranean
formations is achieved by varying the lengths of first and/or second lengths of
casing 310 as will be evident to a skilled artisan.

45 The following example demonstrates the practice and utility of the present
30 invention, but is not to be construed as limiting the scope thereof.

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EXAMPLE

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A well is drilled with a 7.875" bit to 4,000 feet with 11 lb./gal drilling mud and 9.625" surface casing is set at 500 feet. Open hole logs are run and analyzed, along with other information such as geologic offset data, drilling data, and mud logs. It is determined three potential oil productive intervals exist in the well. A carbonate formation is located from 3,700 feet to 3,715 feet and is believed to have low productivity unless stimulated. A sandstone formation is located from 3,600 feet to 3,610 feet and is believed to have low productivity unless stimulated. A highly fractured carbonate is located from 3,500 feet to 3,510 and is believed to not require any stimulation. All of the above depths are based upon open hole logs. An embodiment of the assembly of the present invention is run with 3.5" outside diameter casing and cement float equipment located on the end of the casing. The assembly also contains three externally mounted 2.375" outside diameter perforating guns oriented to shoot into both the casing and the formation, all loaded with 6 shaped charges per foot. Perforating Assembly A contains 15 feet of perforating shaped charges, while Perforating Assemblies B and C contain 10 feet of perforating shaped charges. A flapper valve with the flapper made of ceramic, Assembly D, is also utilized. Approximately 100 feet of casing, with the cement float equipment extends below the connector to Perforating Assembly A. The equipment is positioned utilizing specialty connectors on the 3.5" casing and spacer pipe, and utilizing the top perforating charge in Assembly A as a reference point such that flapper valve Assembly D is 80 feet in distance from the reference point, the top of Perforating Assembly B is 100 feet in distance from the reference point, and Perforating Assembly C is 200 feet in distance from the reference point. Hydraulic control line is connected to all of appropriate assemblies and run into the borehole with the additional lengths of 3.5" casing required to comprise the complete casing string by placing steel bands around the control line and the casing every 30 feet up the wellbore.

The casing string is run into the wellbore until pipe measurements suggest the top of Perforating Assembly A is located at 3,700 feet pipe measurement. The well is circulated with drilling muds and a gamma ray casing

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5 collar log is run to determine the relative position of the Perforating Assembly
A to open hole logging depths. Based upon correlations, it is determined the
equipment and casing needs to be lowered into the wellbore an additional 5 feet
10 to be exactly on depth and the logging tool is removed from the well. The pipe
5 is lowered into the wellbore a total of 6 feet, as engineering calculations suggest
casing movement will contract the string approximately one foot during
cementing operations. The casing is landed on the wellhead equipment and
15 cemented into the open hole by pumping 15.8 lb./gal. cement in sufficient
quantity to fill the entire annulus, and the cement is displaced with a 9.0 lb/gal
20 brine to the cement float equipment.

20 At some later date in time, when the cement has cured, Perforating
Assembly A is detonated by connecting on surface to the hydraulic control line
that is cemented outside of the casing and applying 1500 psi surface pressure
to actuate the pressure actuated firing head. It may be desired to attempt to
25 allow this interval to flow into the interior of the casing and up the casing to
surface to obtain preliminary reservoir information. This lowermost interval of
the well is then acid stimulated by pumping 10,000 gallons of 15% hydrochloric
acid at 3,500 psi at 5 barrels per minute injection rate. The acid is displaced
30 with the first stage of a fracturing fluid which will be utilized to stimulate the
20 second interval, from 3,600 feet to 3,610 feet. Displacement of the acid is
ceased while the last portion of the acid remains located from the lowermost
perforations (3,700 feet to 3,715 feet) to 3,300 feet. Perforating Assembly B is
35 immediately detonated by applying 2,500 psi surface pressure to actuate this
pressure actuated firing head. This perforating event allows interior casing
25 hydrostatic pressure to enter the interior of Perforating Assembly B and transfer
down the secondary line to actuate and close flapper valve Assembly D. This
interval is also perforated with acid across from the perforations, which can aid
40 in dissolving crushed cement from the perforating event. A sand laden
hydraulic fracture stimulation (30,000 pounds of sand in 12,000 gallons of
45 fracturing fluids) is subsequently pumped into this middle interval of the well and
30 displaced to the perforations with brine. Perforating Assembly C is
subsequently detonated by applying 3,500 psi surface pressure to actuate this

5 pressure actuated firing head. All three intervals are produced together up the casing to surface. At a later date it is determined by wireline work down the interior of the casing that no sand is lodged on top of the flapper valve
10 Assembly D. Flow to surface is ceased and a 1" diameter bar by 10 feet in length is dropped and breaks the flapper valve into fragments. The well is then returned to production.

15 The process and assembly of the present invention may also involve the use of propellant material in conjunction with the perforating gun assembly to substantially simultaneously enhance the effectiveness of the resulting
20 perforations and to stimulate the subterranean formation(s). In accordance with this embodiment, propellant in the form of a sleeve, strip, patch or any other configuration is outside of the perforating assembly and casing and in the path in which at least one of the explosive charges in at least one perforating assembly which is utilized in the process of the present invention is aimed. The
25 propellant material may be positioned on either one or more perforating assembly 20, 120, 220 or 350 or casing 12, 112, 212 or 310, respectively. Upon detonation of an explosive charge in a perforating assembly, propellant material which is positioned in the path in which the explosive charge is aimed breaks apart and ignites due to the shock, heat, and pressure of the detonated
30 explosive charge. When one or more explosive charges penetrate a subterranean formation, pressurized gas generated from the burning of the propellant material enters the formation through the recently formed perforations thereby cleaning such perforations of debris. These propellant gases also stimulate the formation by extending the connectivity of formation
35 with the well bore by means of the pressure of the propellant gases fracturing the formation. Additionally or alternatively, the carrier of perforating assembly, e.g. charge carrier 352, may be constructed of propellant material which ignites upon detonation of the explosive charge. Disintegration of the carrier upon
40 ignition may assist the connectivity between perforations formed via perforating gun assemblies having multiple explosive charges. Preferably, the propellant material is a cured epoxy, carbon fiber composite having an oxidizer
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5 incorporated therein such as that commercially available from HTH Technical
Services, Inc. of Coeur d'Alene, Idaho.

10 In addition to the equipment, such as a gamma ray logging tool
mentioned above, the assembly of the present invention may also include other
5 equipment, for example temperature and pressure gauges, which are
positioned on the exterior of the casing of the assembly and connected to the
signal device 18, if necessary to power the equipment. The use of a gamma
15 ray logging tool, pressure gauge and temperature gauge can provide invaluable
real time information to enable a skilled artisan to monitor fracture growth where
10 the subterranean formation(s) are fracture using the processes and assembly
of the present invention.

20 While the foregoing preferred embodiments of the invention have been
described and shown, it is understood that the alternatives and modifications,
such as those suggested and others, may be made thereto and fall within the
25 scope of the invention.

Claims

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CLAIMS

I claim:

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1 1. A process for establishing fluid communication comprising:
2 positioning at least one explosive charge in a subterranean well bore
3 such that said at least one explosive charge is placed external to casing which
4 is also positioned within said well bore and is aimed toward said casing; and
15 5 detonating said at least one explosive charge so as to perforate the wall
6 of said casing at least once.

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1 2. The process of claim 1 wherein said explosive charge perforates the wall of
2 said casing twice.

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1 3. The process of claim 1 further comprising:
2 cementing said at least one explosive charge and said casing in said well
3 bore prior to the step of detonating.

1 4. The process of claim 1 wherein said at least one explosive charge is
2 positioned in said subterranean well bore substantially simultaneously with said
3 casing.

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1 5. A process for completing a subterranean well bore comprising:
2 penetrating the wall of a casing which is positioned and cemented within
3 a subterranean well bore from the exterior of the casing to the interior.

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1 6. A process for completing a subterranean well comprising:
2 positioning at least one explosive charge in a subterranean well bore
3 outside of casing; and
4 detonating said at least one explosive charge so as to perforate said
5 casing.

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1 7. The process of claim 6 further comprising:
2 positioning said at least one explosive charge adjacent a subterranean
3 formation, the step of detonating said at least one explosive charge also
4 perforates said subterranean formation.

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1 8. The process of claim 7 further comprising:
2 injecting fluid through the casing and into said subterranean formation.

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1 9. The process of claim 7 further comprising:

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2 producing fluid from said subterranean formation into the casing.
- 1 10. The process of claim 6 further comprising:
2 cementing said at least one explosive charge and said casing in said
10 3 subterranean well bore prior to the step of detonating.
- 1 11. The process of claim 10 further comprising:
2 positioning said at least one explosive charge adjacent a subterranean
3 formation, the step of detonating said at least one explosive charge also
15 4 perforates said cement and said subterranean formation.
- 1 12. The process of claim 11 further comprising:
2 injecting fluid through the casing and into said subterranean formation.
- 20 1 13. The process of claim 11 further comprising:
2 producing fluid from said subterranean formation into the casing.
- 1 14. The process of claim 6 further comprising:
2 positioning at least one tool in said subterranean well bore outside said
25 3 casing for monitoring conditions of said well bore or a subterranean formation,
4 wherein said tool is a logging tool, a temperature gauge or a pressure gauge.
- 1 15. The process of claim 14 further comprising:
30 2 cementing said at least one tool, said at least one explosive charge and
3 said casing in said subterranean well bore prior to the step of detonating.
- 1 16. The process of claim 6 further comprising:
2 positioning at least two explosive charges in a subterranean well bore
35 3 outside of casing, one of said at least two explosive charges being positioned
4 adjacent a first subterranean formation while another of said at least two
5 explosive charges being positioned adjacent a second subterranean formation;
40 6 detonating said one of said at least two explosive charges so as to
7 perforate said casing and said first subterranean formation; and
8 detonating said another of said at least two explosive charges so as to
9 perforate said casing and said second subterranean formation.
- 45 1 17. The process of claim 16 further comprising:
2 cementing said at least two explosive charges and said casing in said
3 subterranean well bore prior to the steps of detonating.
- 50
- 55

- 5
- 1 18. The process of claim 16 wherein said steps of detonating occur
2 substantially simultaneously.
- 10
- 1 19. The process of claim 16 wherein said step of detonating said one of said
2 at least two explosive charges occurs prior to said step of step of detonating
3 said another of said at least two explosive charges.
- 15
- 1 20. The process of claim 16 further comprising:
2 producing fluid from said first subterranean formation into said casing
3 after detonating said one of said at least two explosive charges.
- 20
- 1 21. The process of claim 16 further comprising:
2 producing fluid from said second subterranean into said casing after
3 detonating said another of said at least two explosive charges.
- 25
- 1 22. The process of claim 19 further comprising:
2 injecting fluid through the casing and into said first subterranean
3 formation after detonating said one of said at least two explosive charges and
4 prior to said step of step of detonating said another of said at least two
5 explosive charges so as to treat and/or fracture said first subterranean
6 formation.
- 30
- 1 23. The process of claim 19 further comprising:
2 sealing the interior of said casing to fluid flow between said first and said
3 second formations; and
4 injecting fluid through the casing and into said second subterranean
35 formation after detonating said another of said at least two explosive charges
5 so as to treat and/or fracture said second subterranean formation.
- 40
- 1 24. The process of claim 6 further comprising:
2 placing fluid within said subterranean well bore prior to detonating said
3 at least one explosive charge.
- 45
- 1 25. The process of claim 24 wherein said fluid comprises an acid.
- 2 26. The process of claim 6 further comprising:
3 igniting propellant material by detonating said at least one explosive
charge.
- 50
- 1 27. The process of claim 6 further comprising:
- 55

5
2 positioning control line in said subterranean well bore outside of said
3 casing which is connected to said at least one explosive charge.

10
1 28. A process for providing fluid communication across the wall of a casing
2 comprising:

3 detonating a first perforating gun assembly which is positioned outside
4 of a casing in a subterranean well bore thereby perforating said casing.

15
1 29. The process of claim 28 further comprising:

2 cementing said casing within said well bore.

1 30. A process for completing one or more subterranean formations comprising:

20
2 detonating a first perforating gun assembly which is positioned outside
3 of a casing in a subterranean well bore thereby perforating said casing and a
4 first subterranean formation.

1 31. The process of claim 30 further comprising:

25
2 injecting one or more stimulation and/or treatment fluids via said casing
3 into said first subterranean formation.

1 32. The process of claim 31 wherein said at least one of said one or more
2 stimulation and/or treatment fluids is injected under sufficient pressure to
30
3 fracture said first subterranean formation.

1 33. The process of claim 30 further comprising:

2 detonating a second perforating gun assembly which is positioned
35
3 outside of said casing in a subterranean well bore thereby perforating said
4 casing and a second subterranean formation.

1 34. The process of claim 33 further comprising:

2 injecting one or more stimulation and/or treatment fluids via said casing
40
3 into said second subterranean formation.

1 35. The process of claim 34 further comprising:

2 isolating said first subterranean formation from injection of fluids prior to
45
3 injecting said one or more stimulation and/or treatment fluids via said casing
4 into said second subterranean formation.

5

1 36. The process of claim 35 wherein said at least one of said one or more
2 stimulation and/or treatment fluids is injected under sufficient pressure to
3 fracture said second subterranean formation.

10

1 37. The process of claim 35 further comprising:

2 reversing the step of isolating said first subterranean formation from
3 injection of fluids after injecting one or more stimulation and/or treatment fluids
4 via said casing into said second subterranean formation.

15

1 38. A process for completing a subterranean well comprising:

2 penetrating casing which is positioned in a subterranean well bore while
3 the interior of said casing remains unoccupied by perforating guns or other
4 equipment, tools, tubulars or lines.

20

1 39. A subterranean completion system comprising:

2 a casing which is at least partially positioned within a subterranean well
3 bore; and

25

4 at least one perforating gun assembly which is positioned external to said
5 casing and within said well bore, said perforating gun assembly having at least
6 one explosive charge aimed in the direction of said casing.

30

1 40. The subterranean completion system of claim 39 wherein said at least one
2 perforating gun assembly and said casing are connected.

1 41. The subterranean completion system of claim 39 further comprising:

2 a logging tool, temperature gauge and/or pressure gauge which is
3 positioned external to said casing and within said well bore.

35

1 42. The subterranean completion system of claim 39 further comprising:

2 a signaling device for transmitting signals from the surface of the earth
3 to said perforating gun, said signaling device being positioned external to said
4 casing.

40

1 43. A completion system comprising:

2 a casing; and

3 at least one perforating gun connected to the exterior of said casing and
4 having at least one explosive charge aimed toward said casing.

45

1 44. The completion system of claim 43 further comprising:

50

55

5
2 at least two perforating guns connected to the exterior of said casing,
3 each of said at least two perforating guns having at least one explosive charge
4 aimed toward said casing.

10 1 45. The completion system of claim 44 further comprising:

2 a zone isolation device positioned between said at least two perforating
3 guns for selectively shutting off flow through said casing.

15 1 46. The completion system of claim 45 wherein said zone isolation device is
2 a flapper valve.

1 47. The completion system of claim 46 wherein said flapper valve is
2 constructed of a destructible material.

20 1 48. The completion system of claim 43 further comprising:

2 an assembly for providing signals to said at least one perforating gun
3 which is connected to said perforating gun and is positioned exterior of said
4 casing.

25 1 49. The completion system of claim 48 wherein said assembly is hydraulically
2 connected to said perforating gun.

30 1 50. The completion system of claim 48 wherein said assembly is electrically
2 connected to said perforating gun.

1 51. The completion system of claim 48 wherein said assembly is connected to
2 said perforating gun by wave transmission.

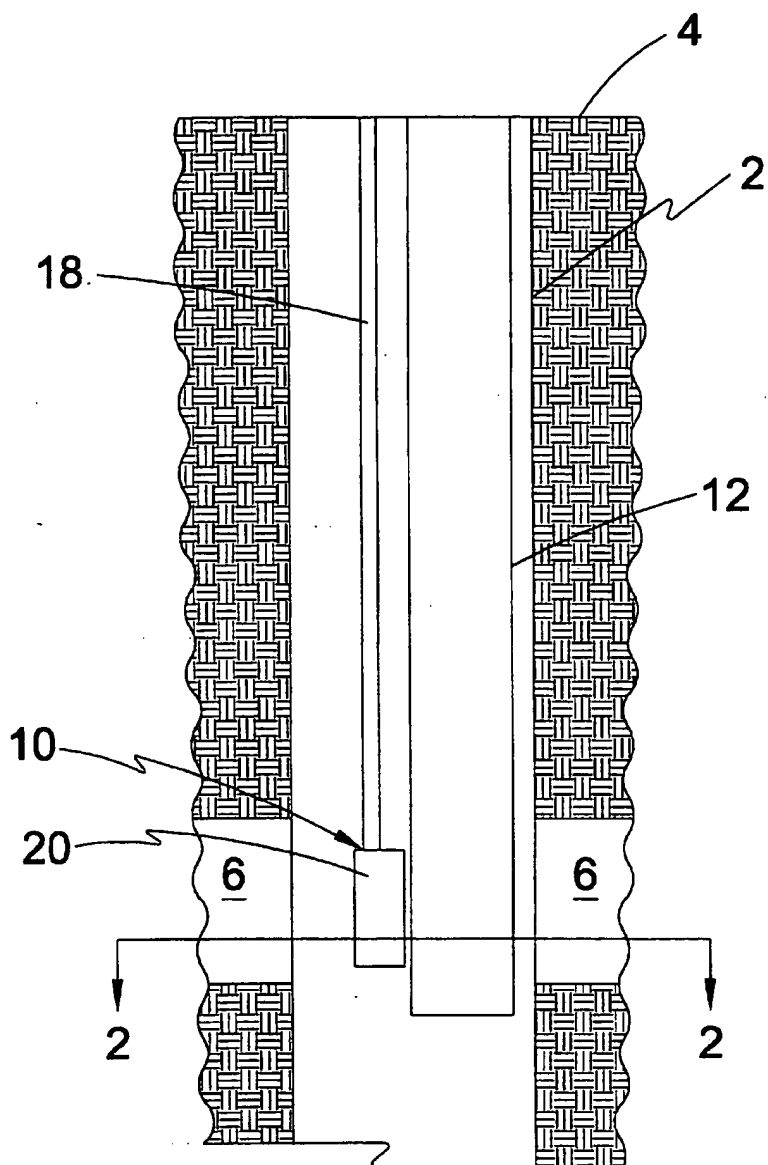


Fig. 1

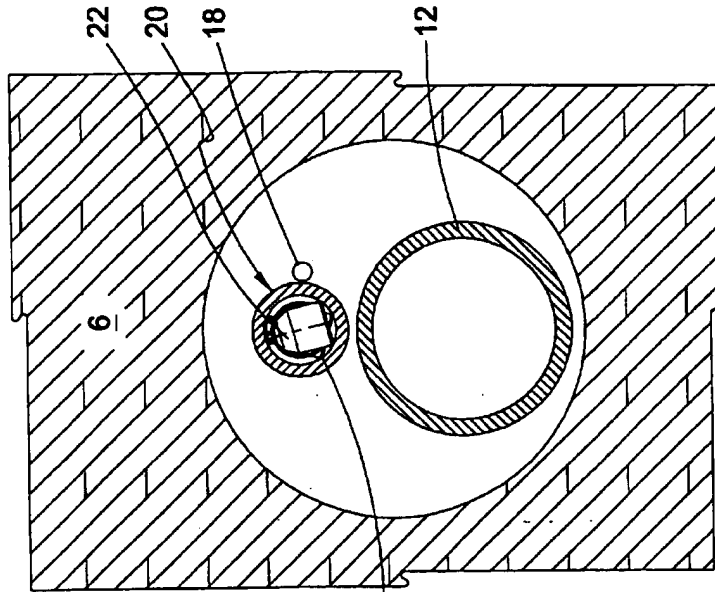


Fig. 2

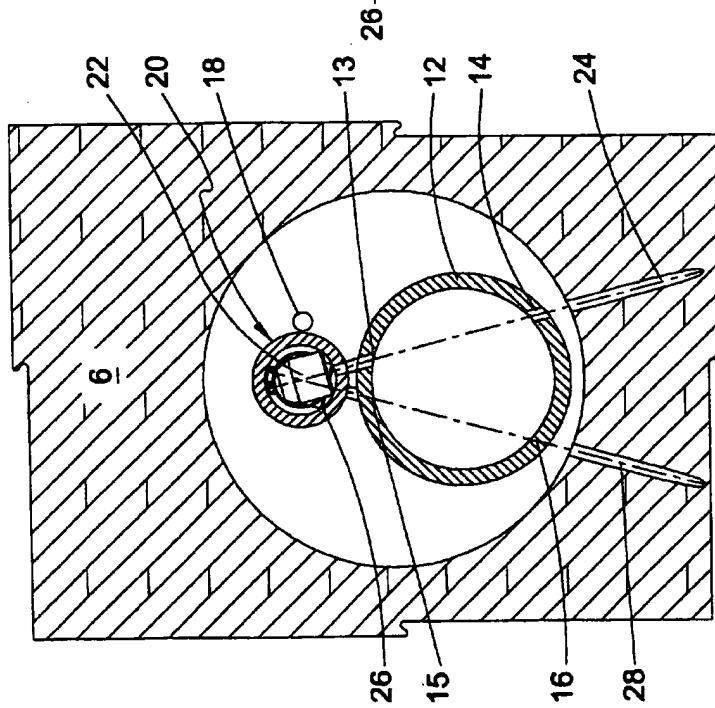


Fig. 3

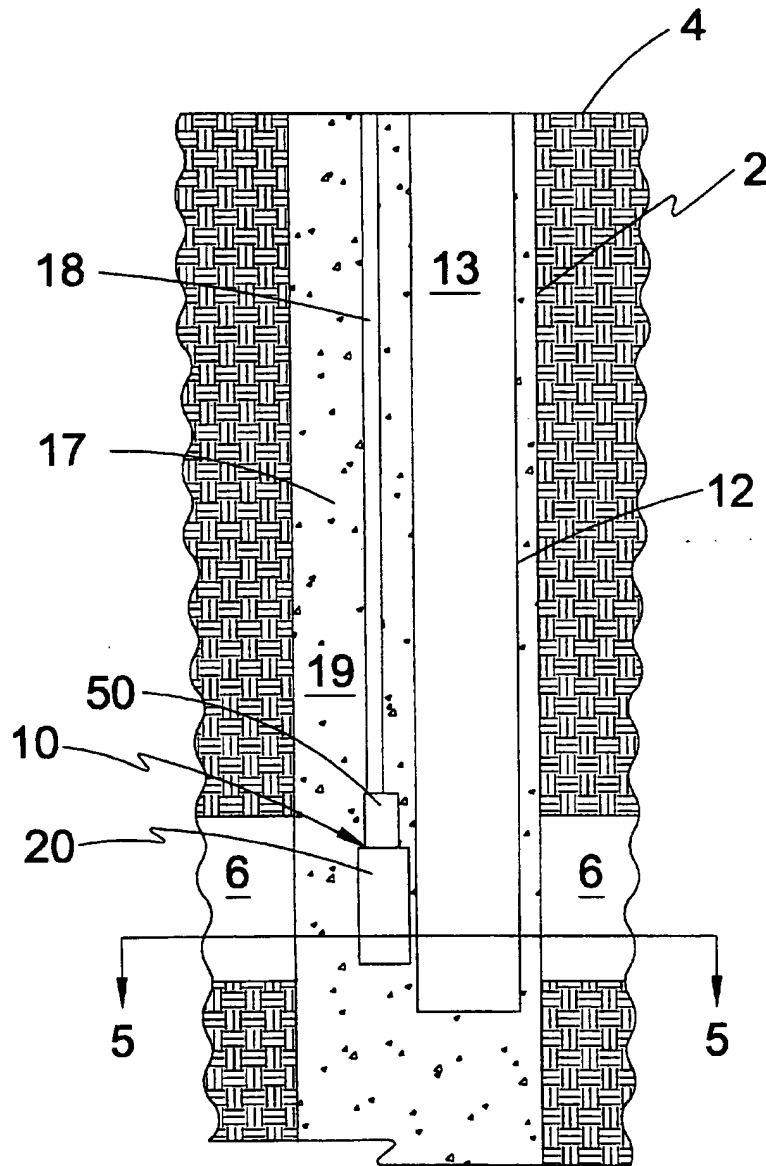


Fig. 4

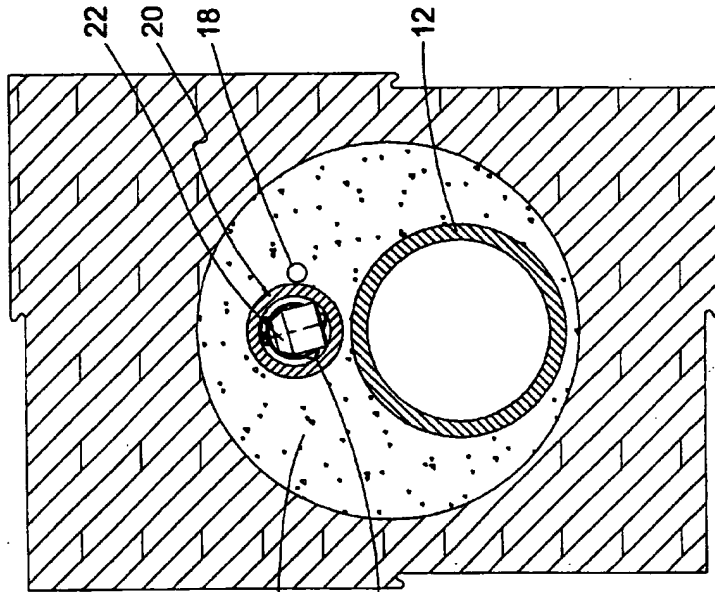


Fig. 5

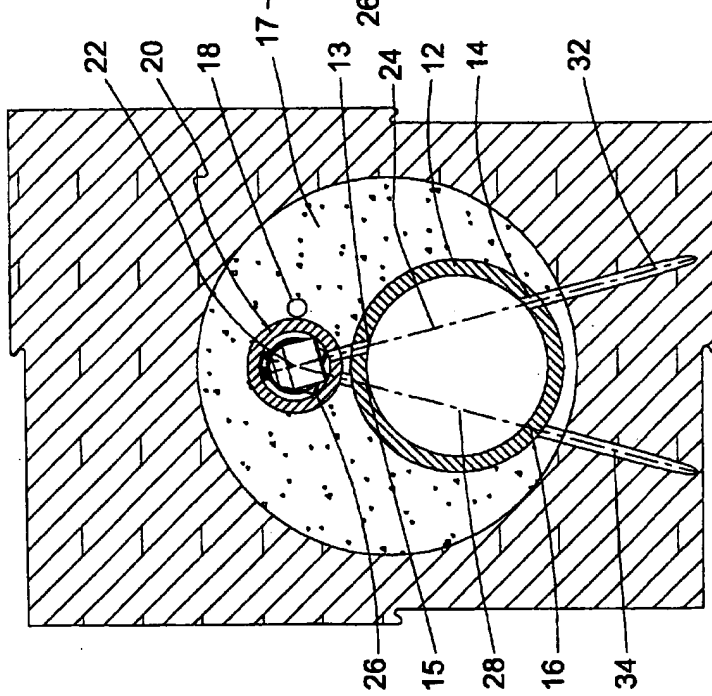


Fig. 6

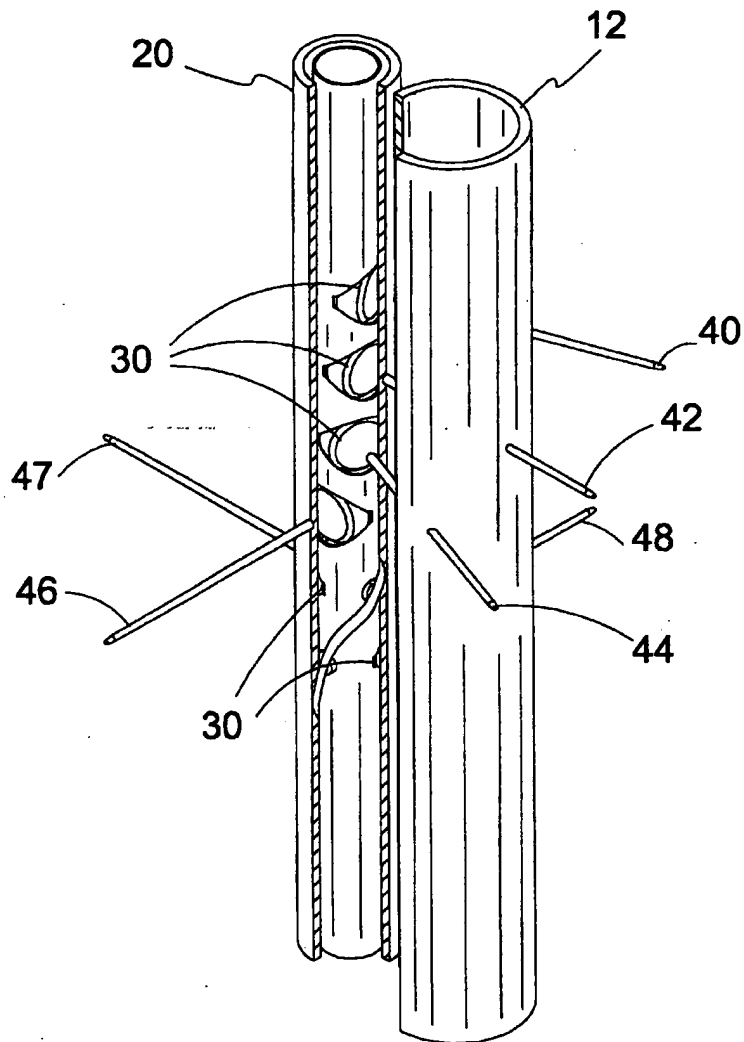


Fig. 7

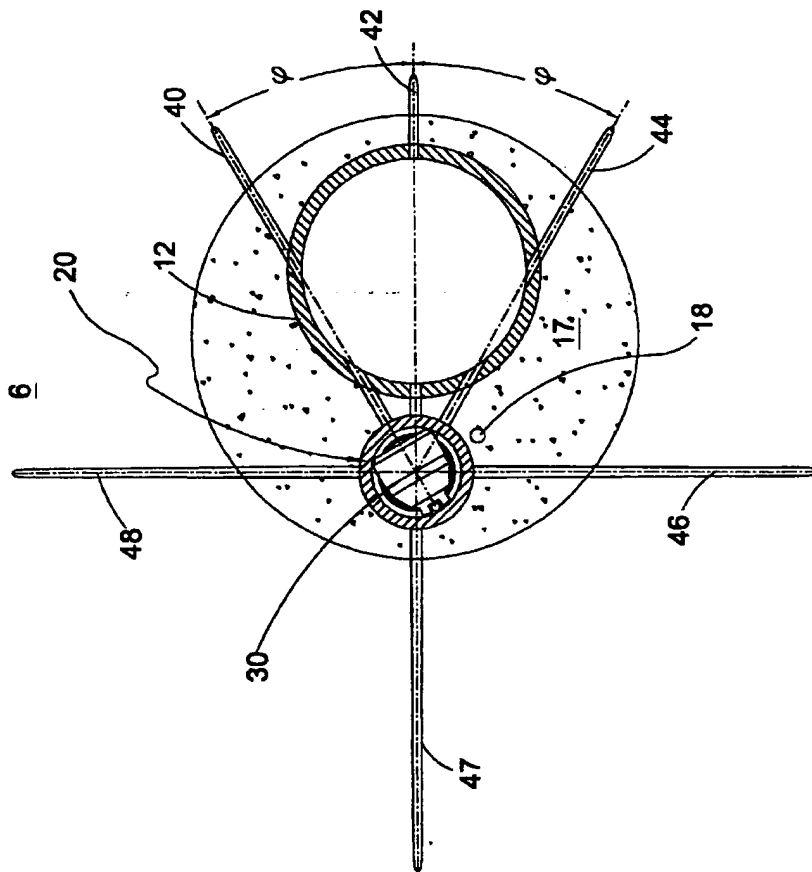


Fig. 8

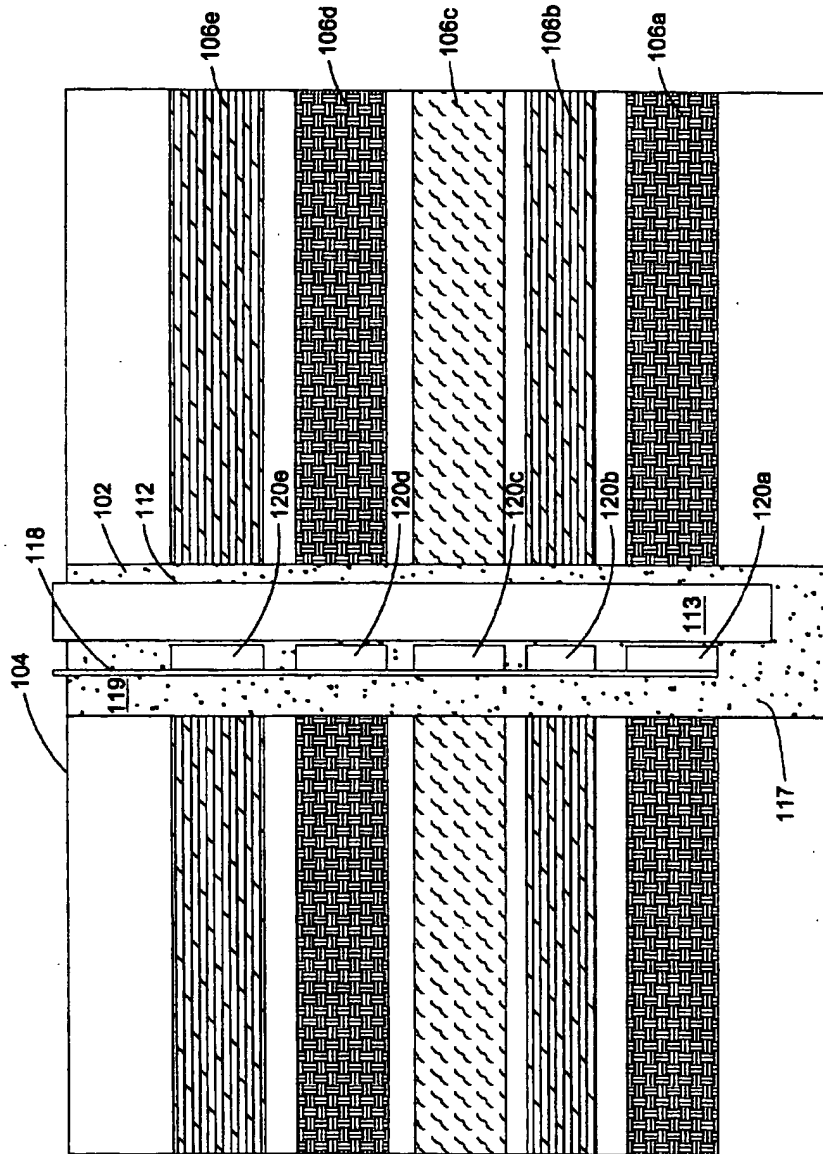


Fig. 9

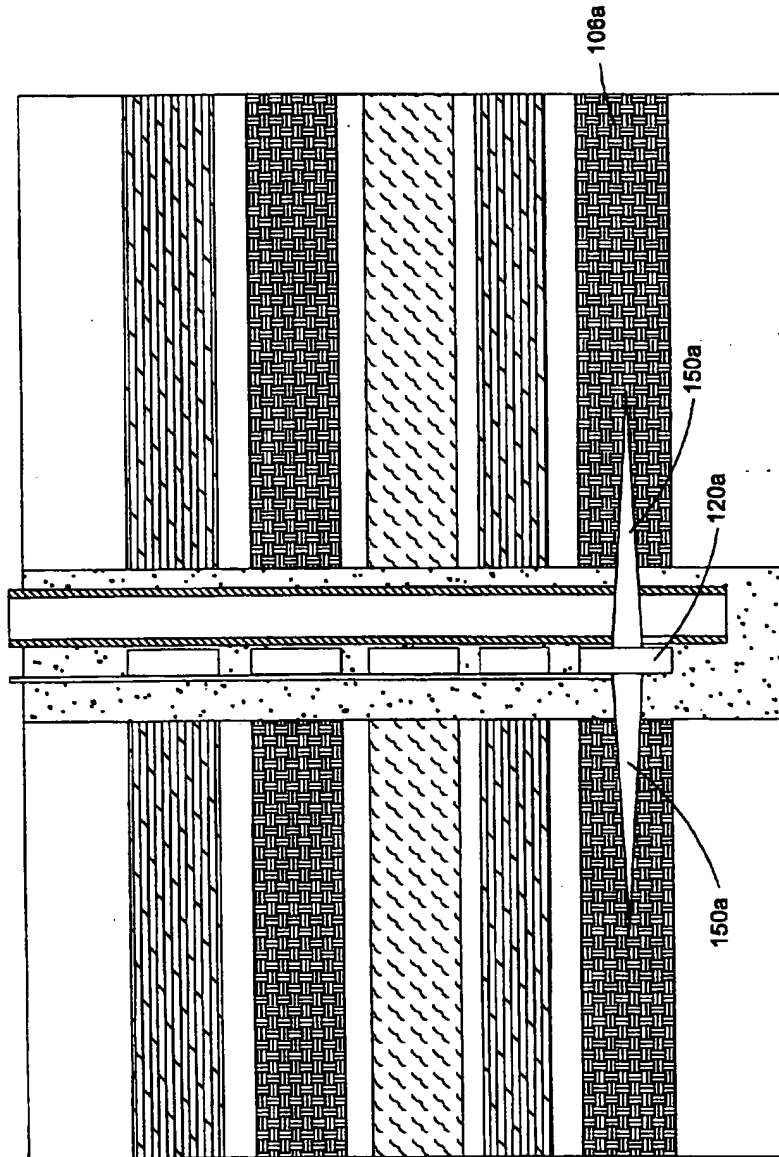


Fig. 10a

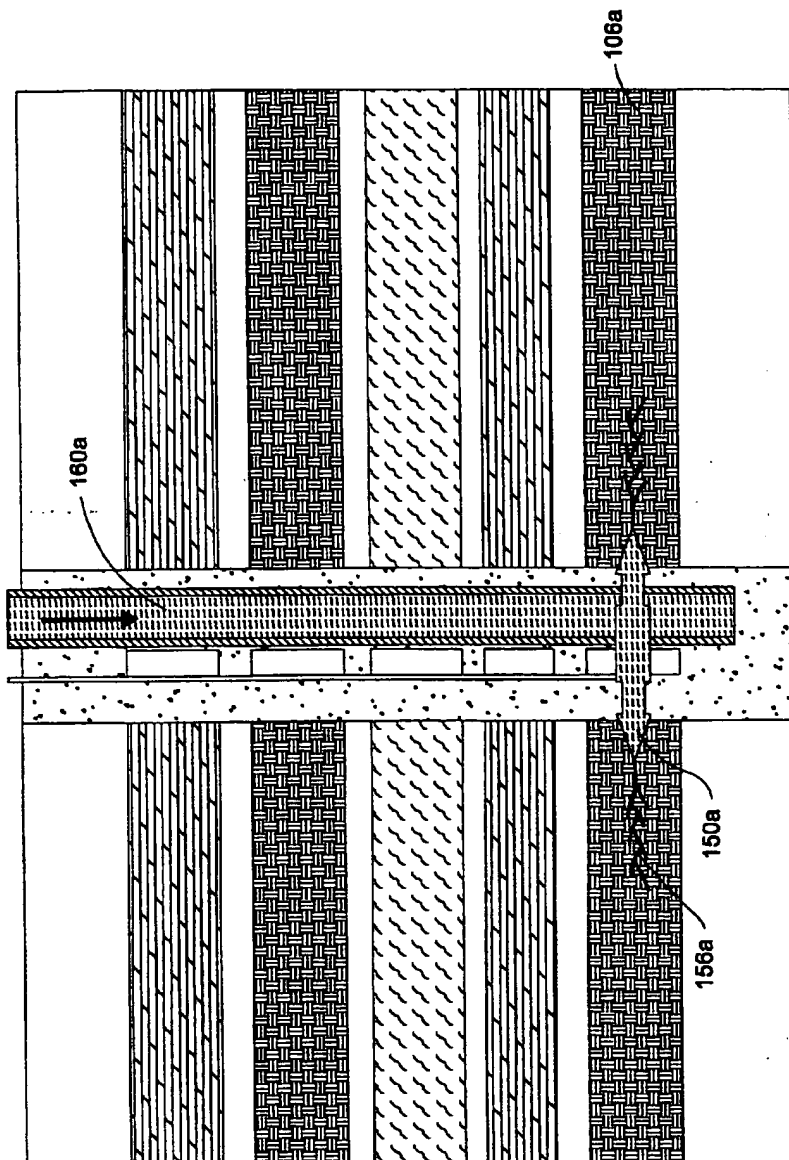


Fig. 10b

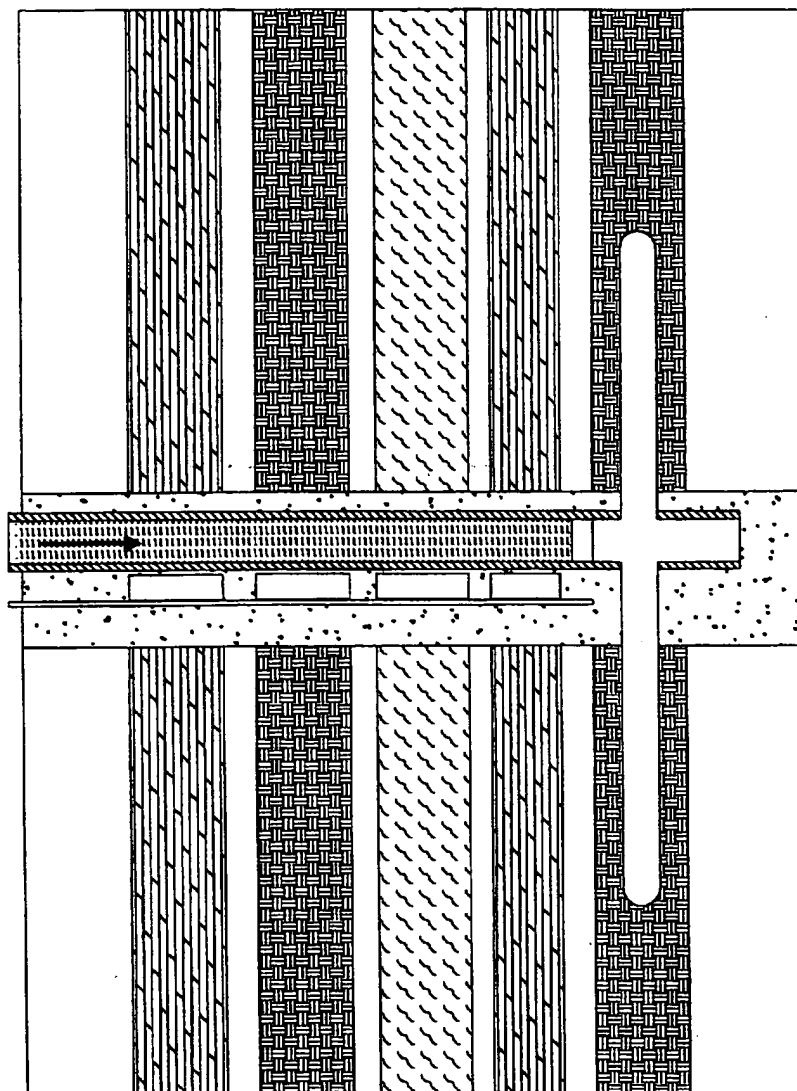


Fig. 10c

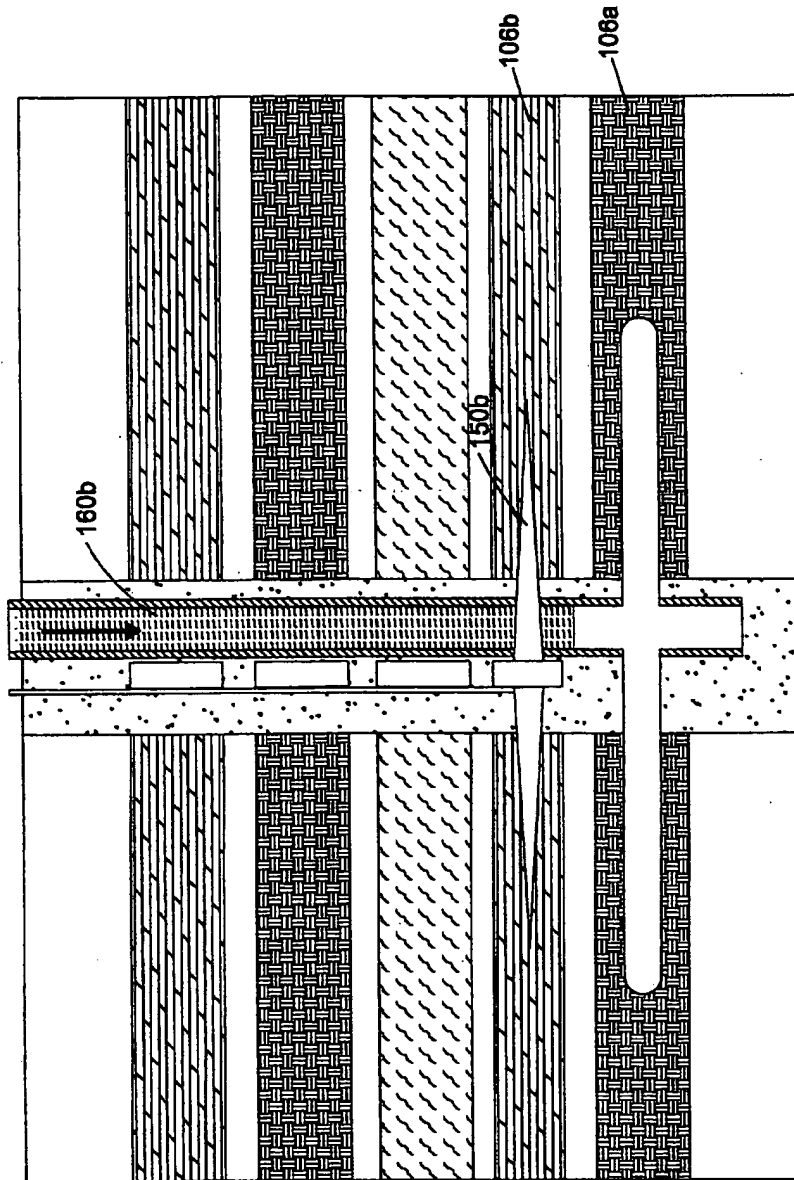


Fig. 10d

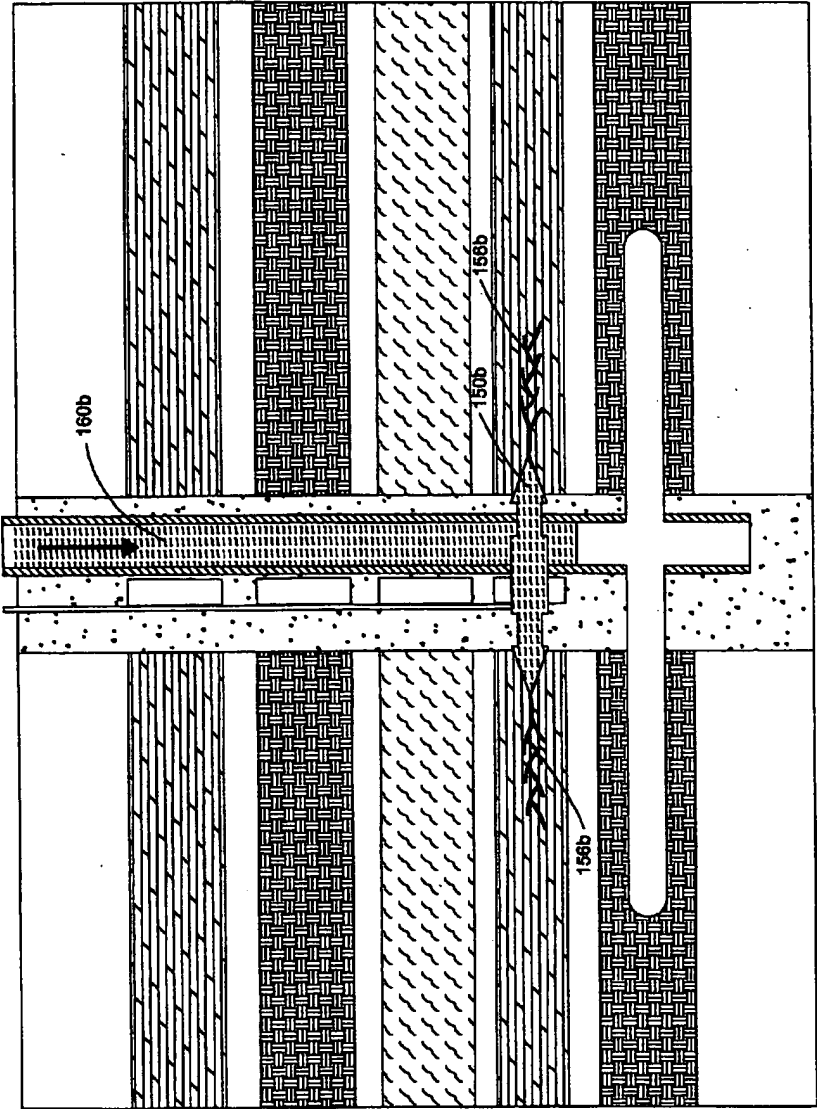


Fig. 10e

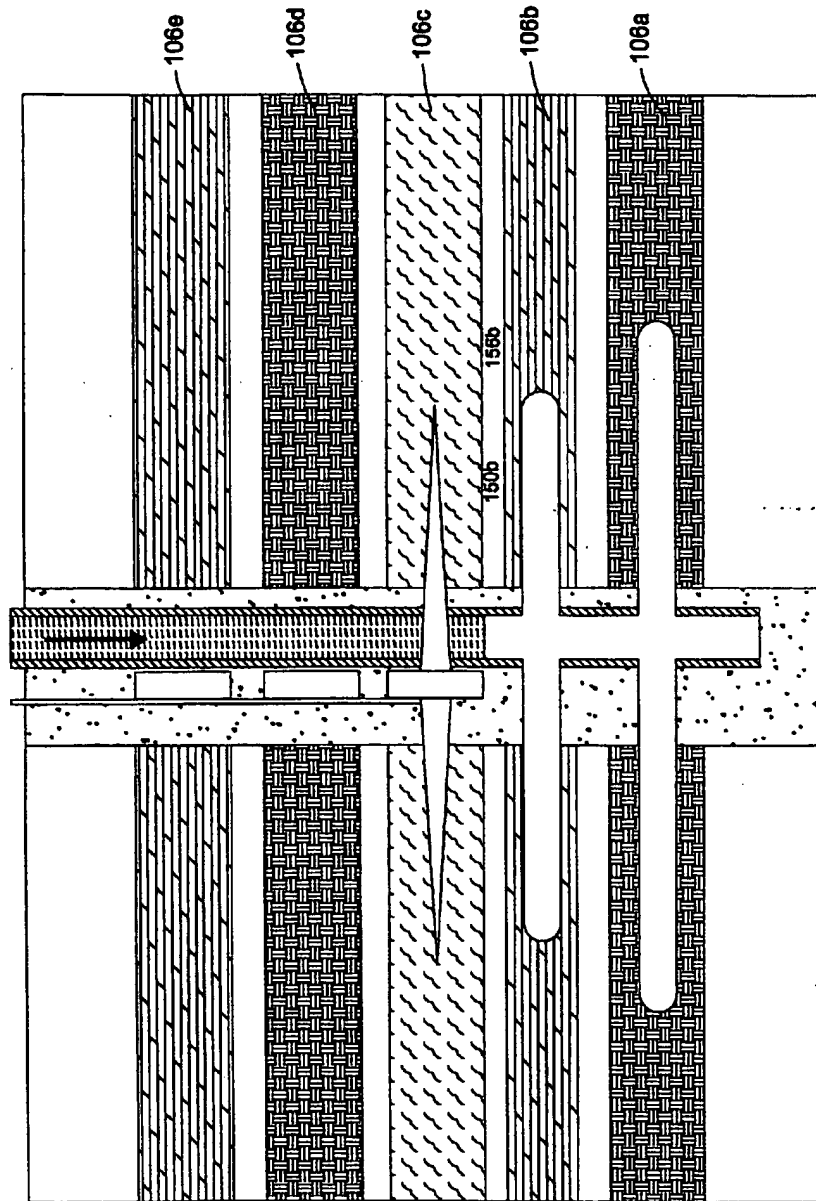


Fig. 10f

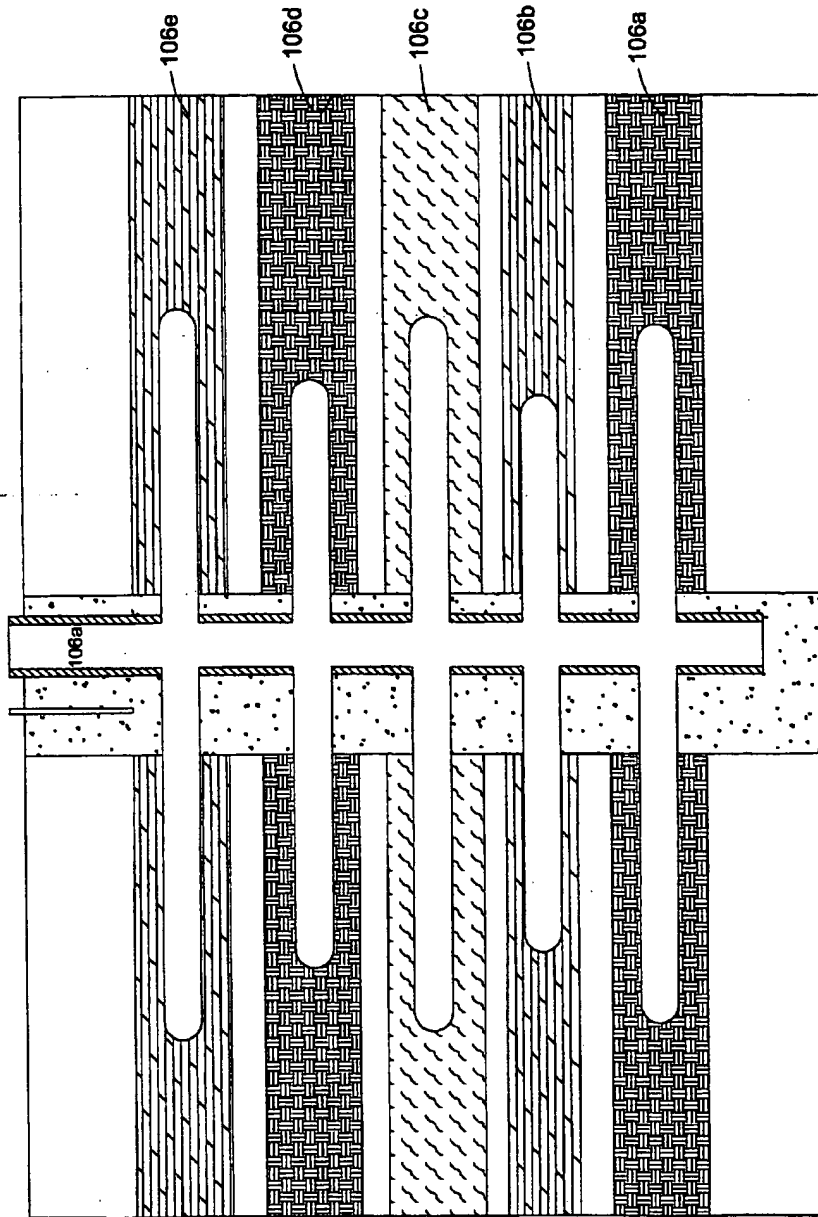


Fig. 10g

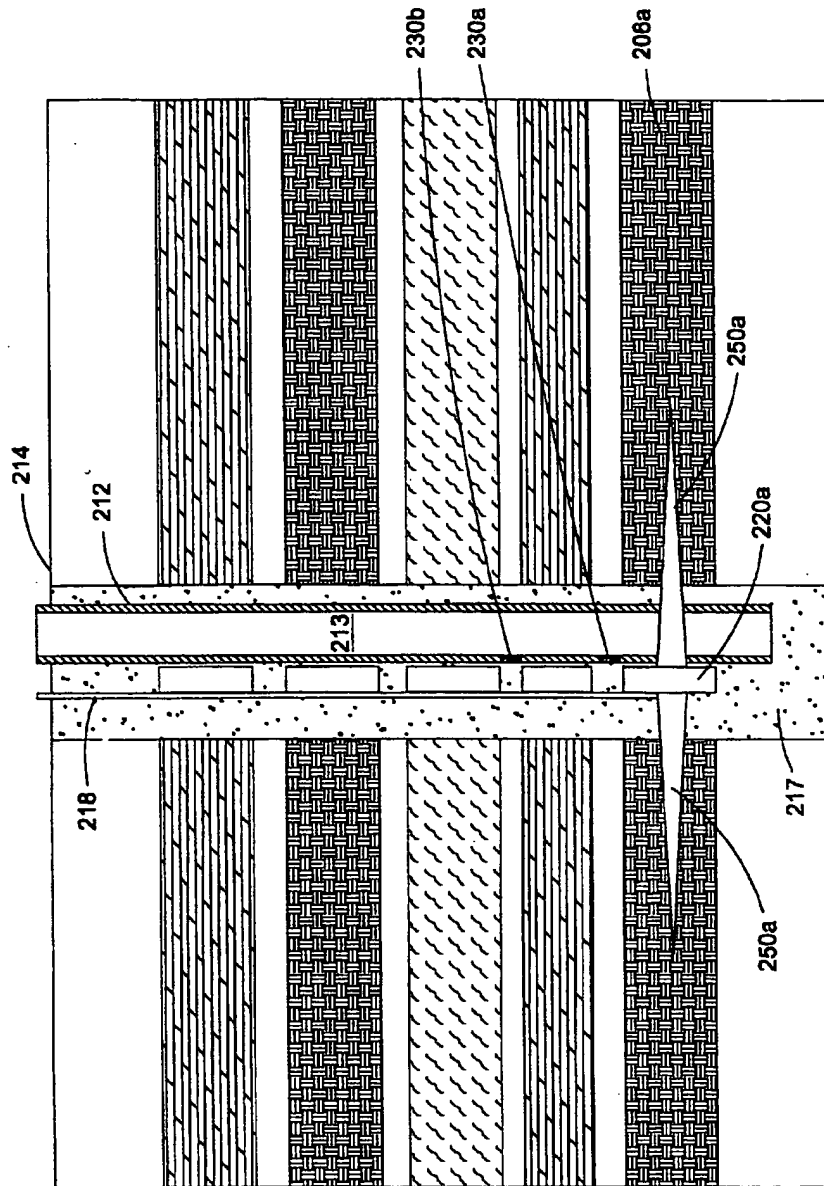


Fig. 11a

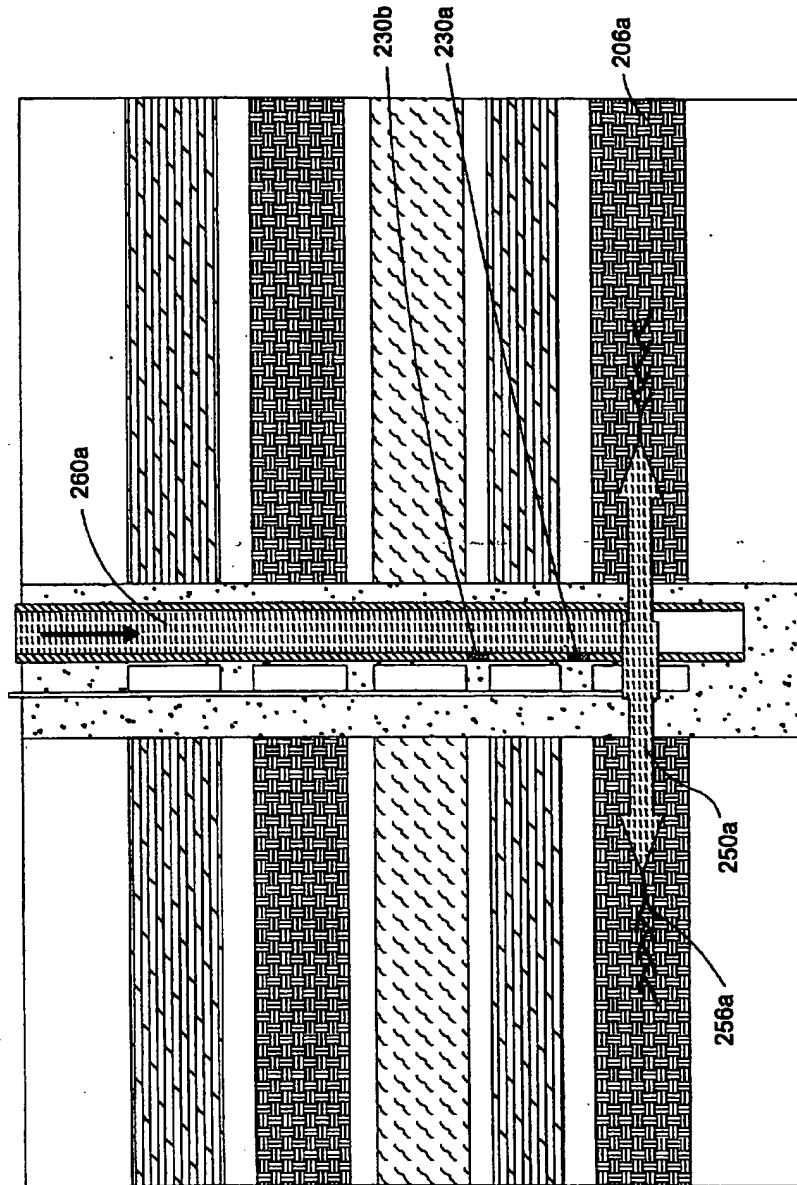


Fig. 11b

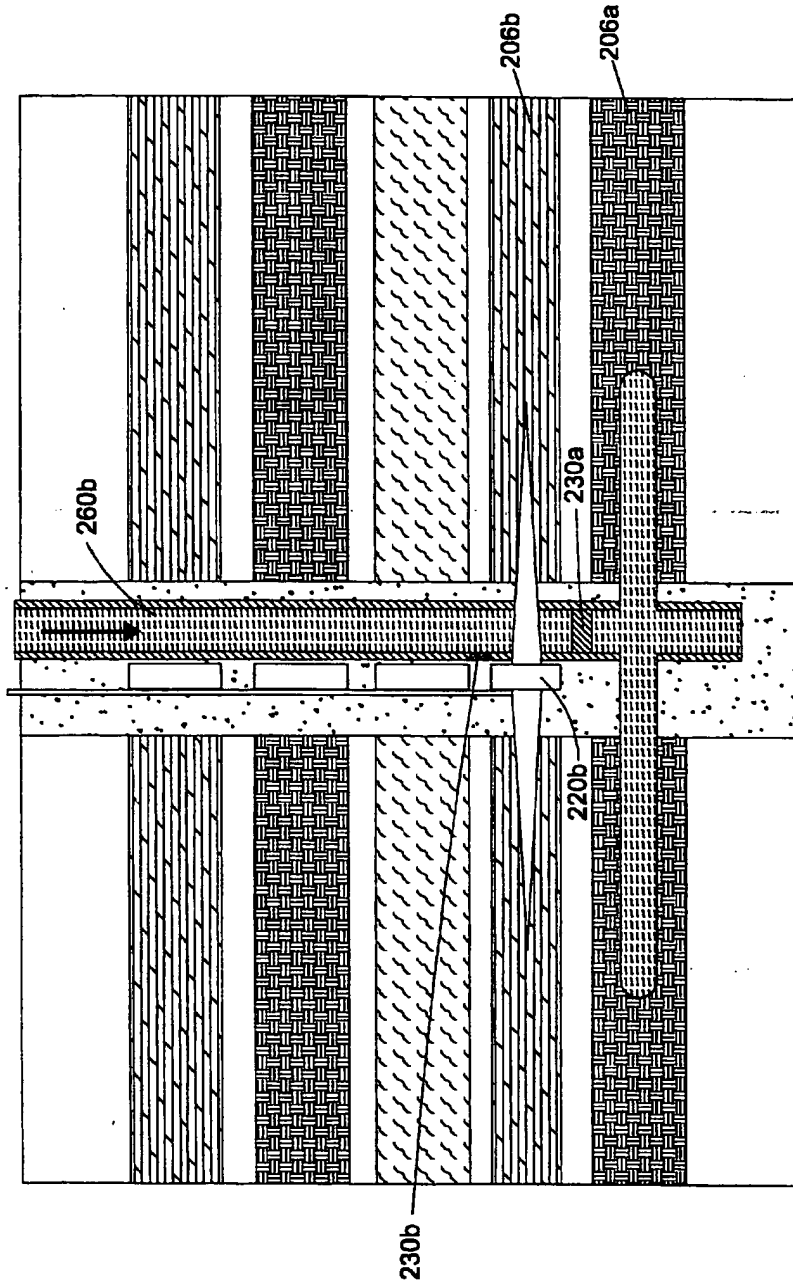


Fig. 11c

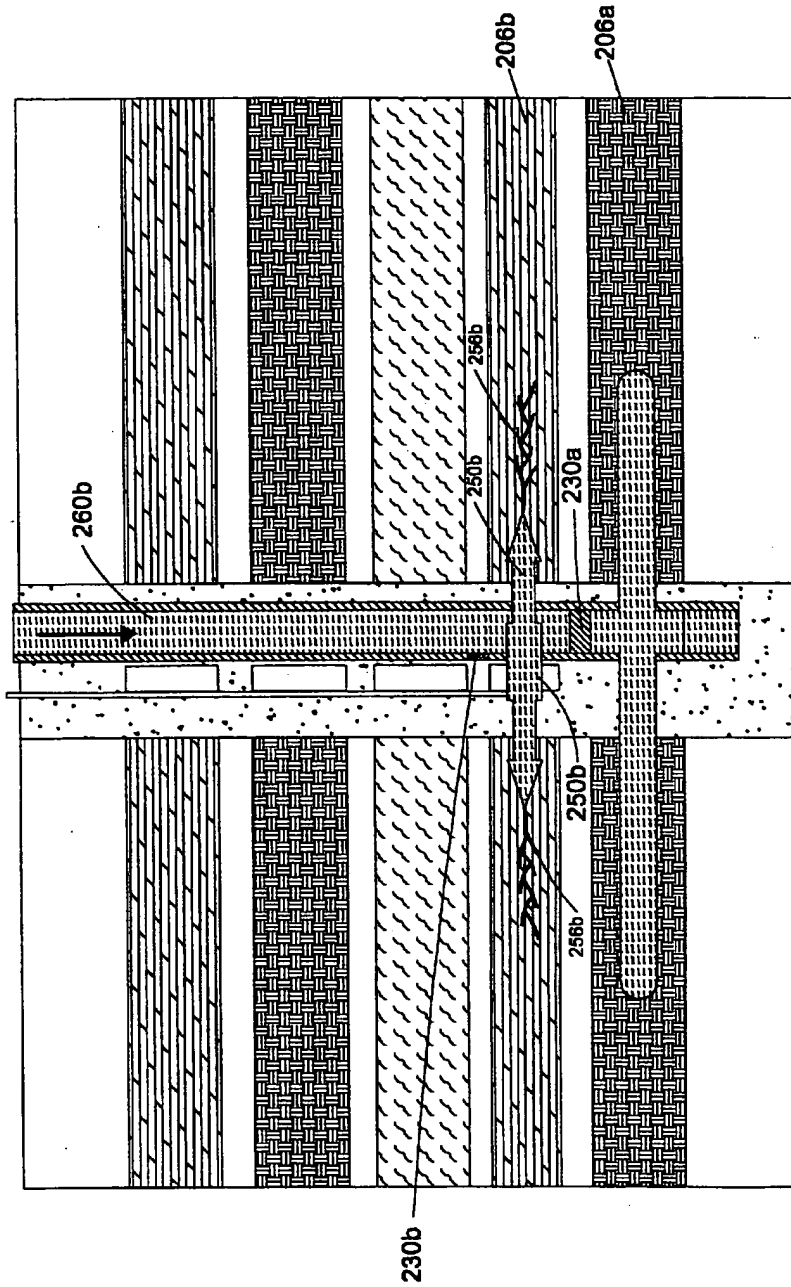


Fig. 11d

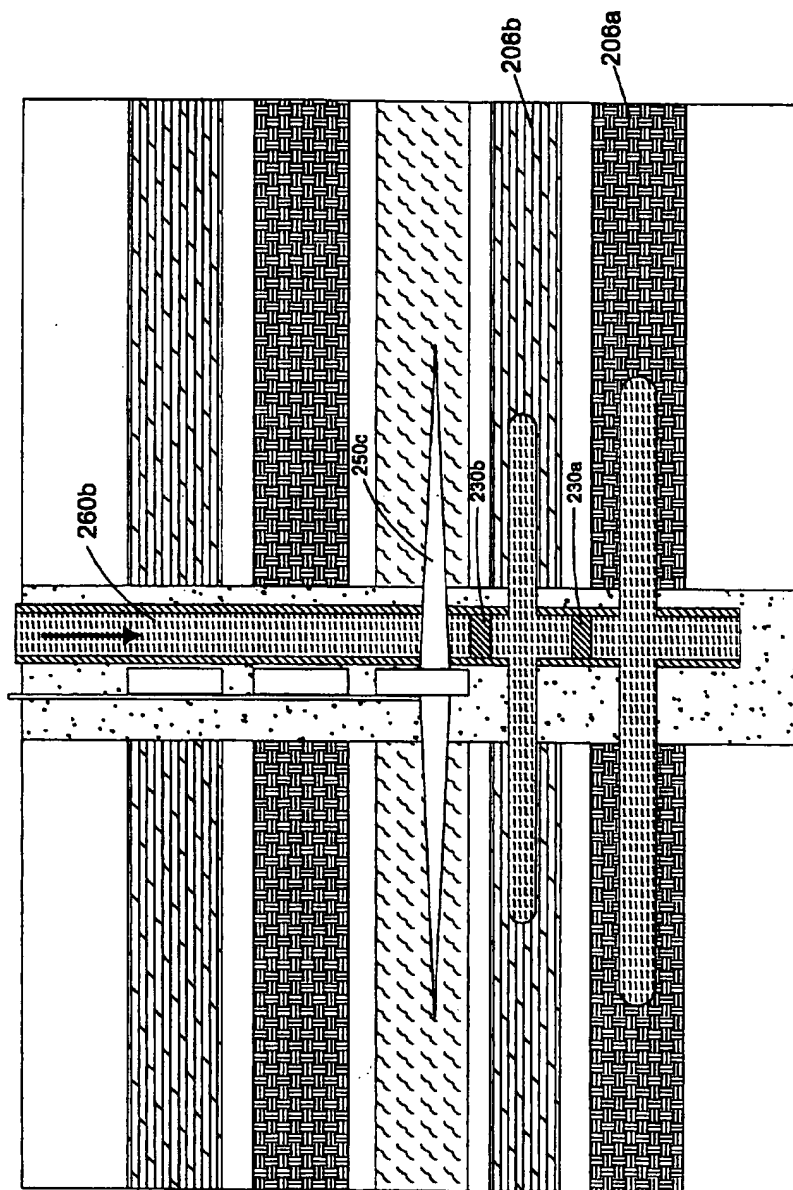


Fig. 11e

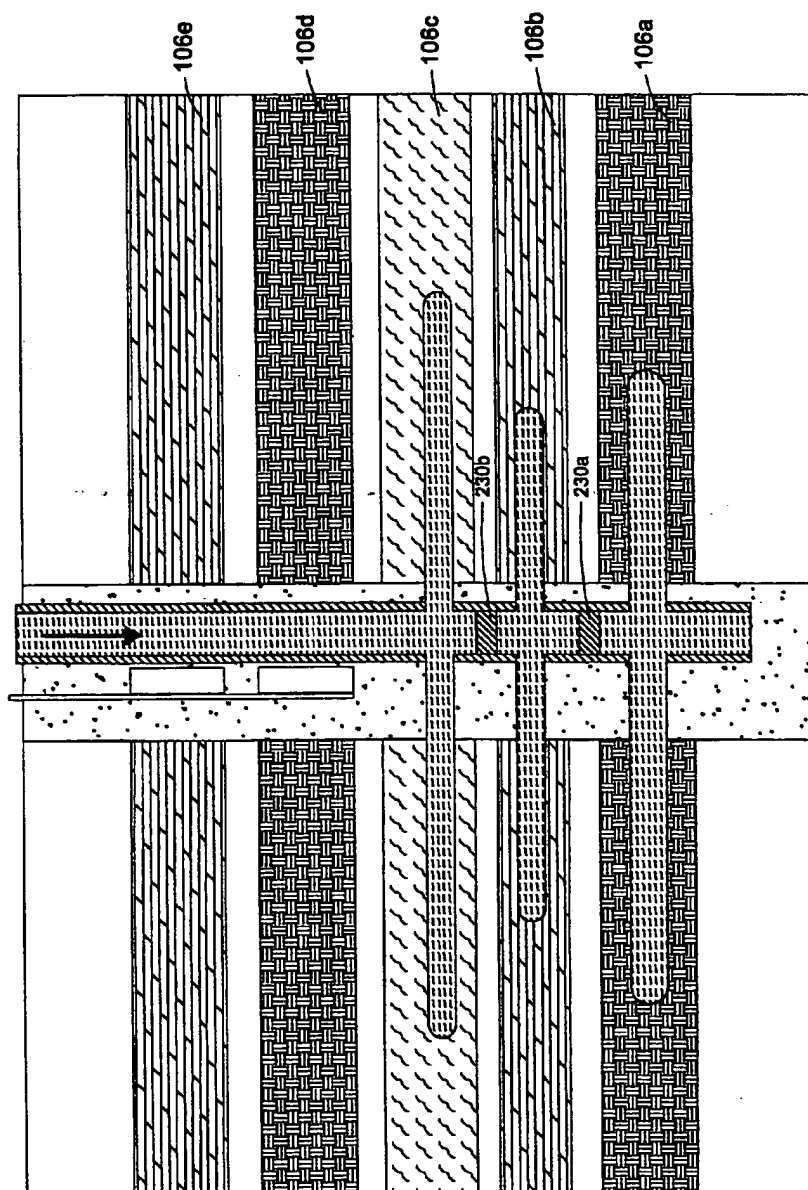


Fig. 11f

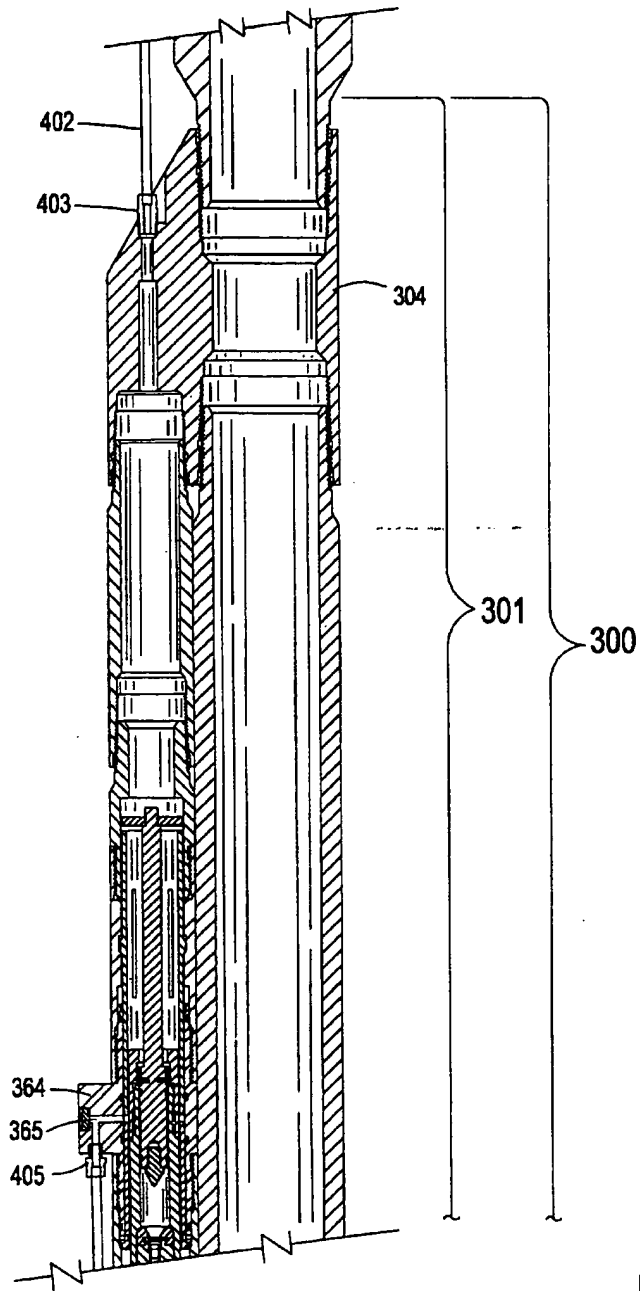


Fig. 12 a

Fig. 12b

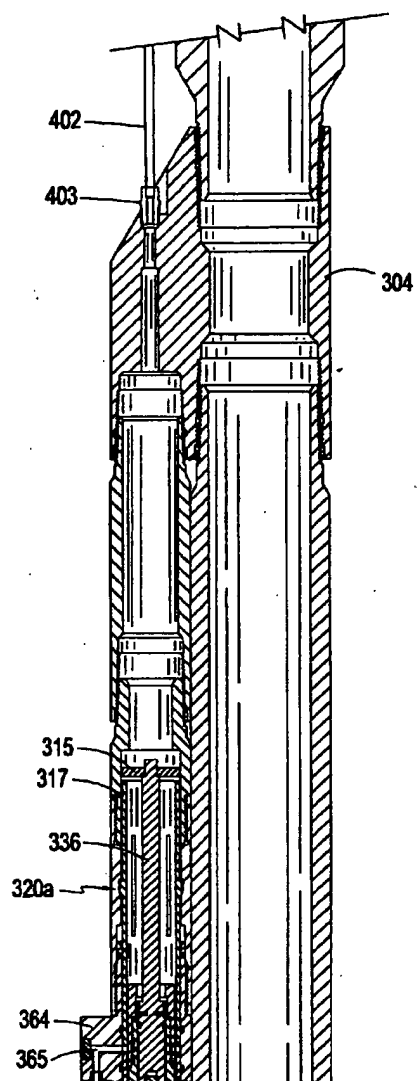
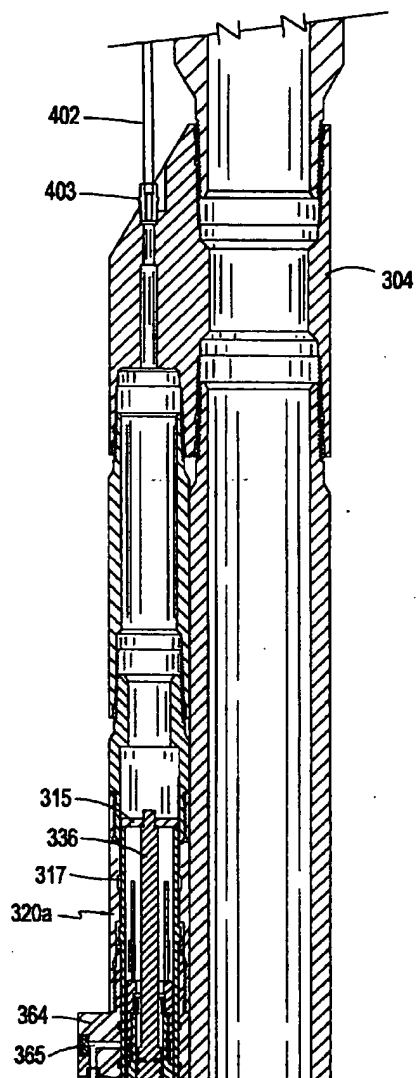


Fig. 12c



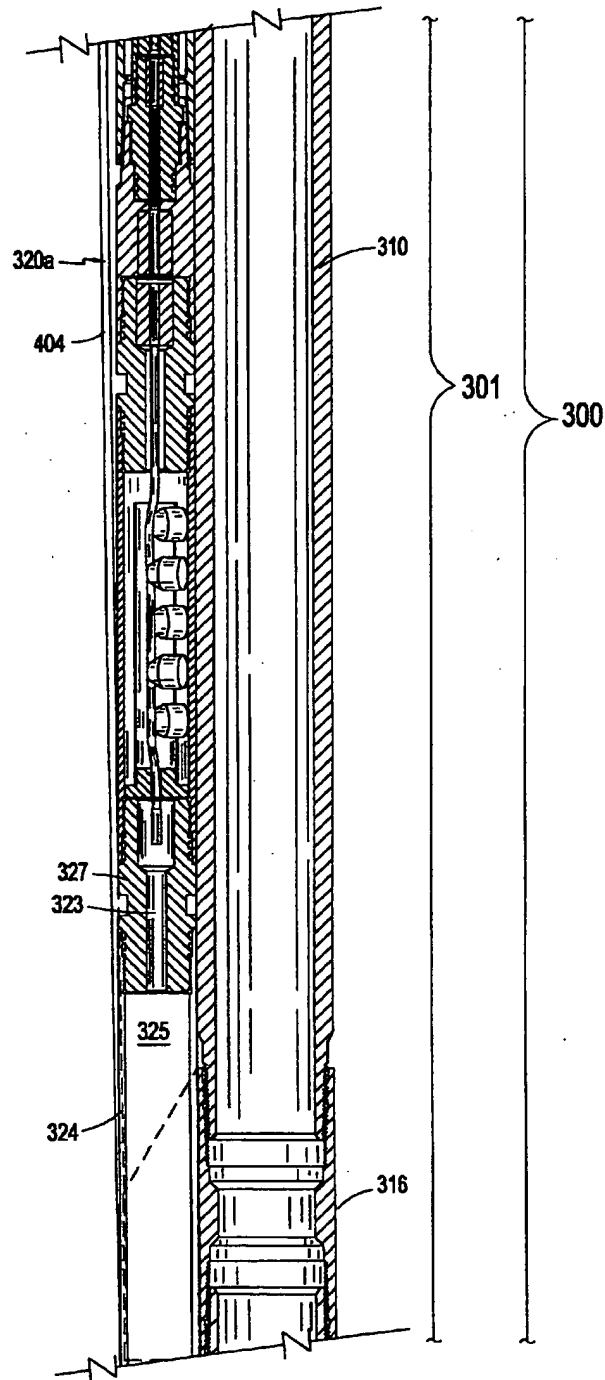
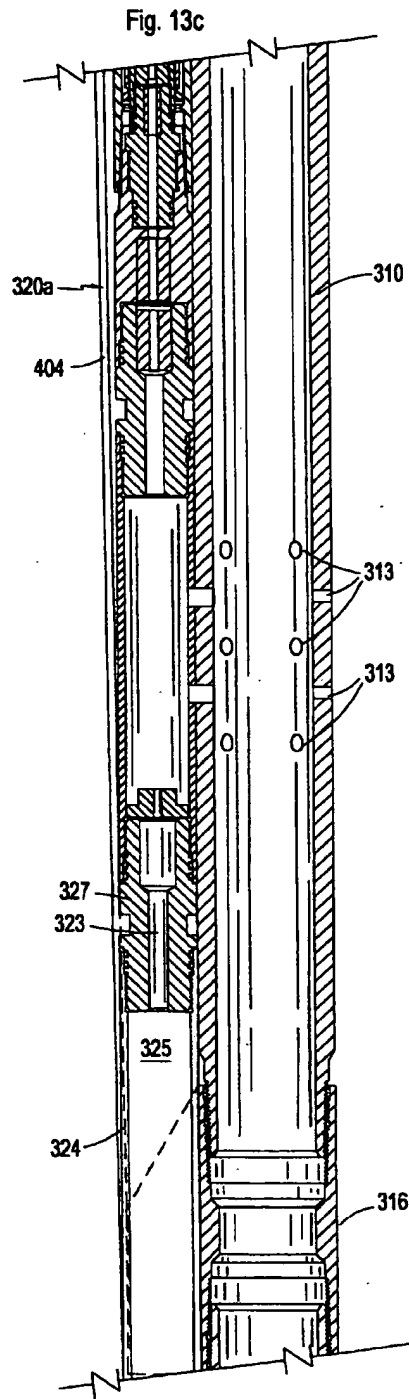
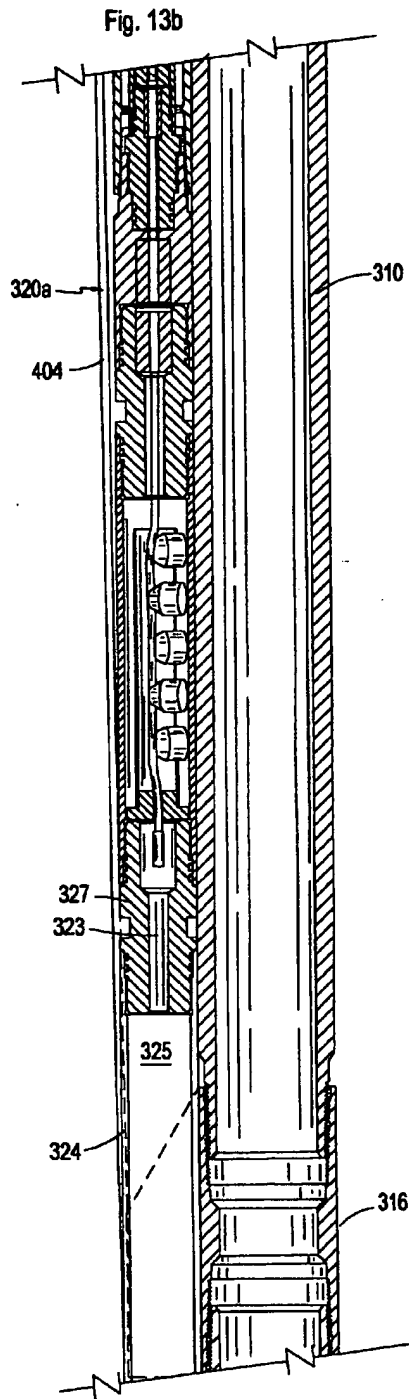


Fig. 13 a



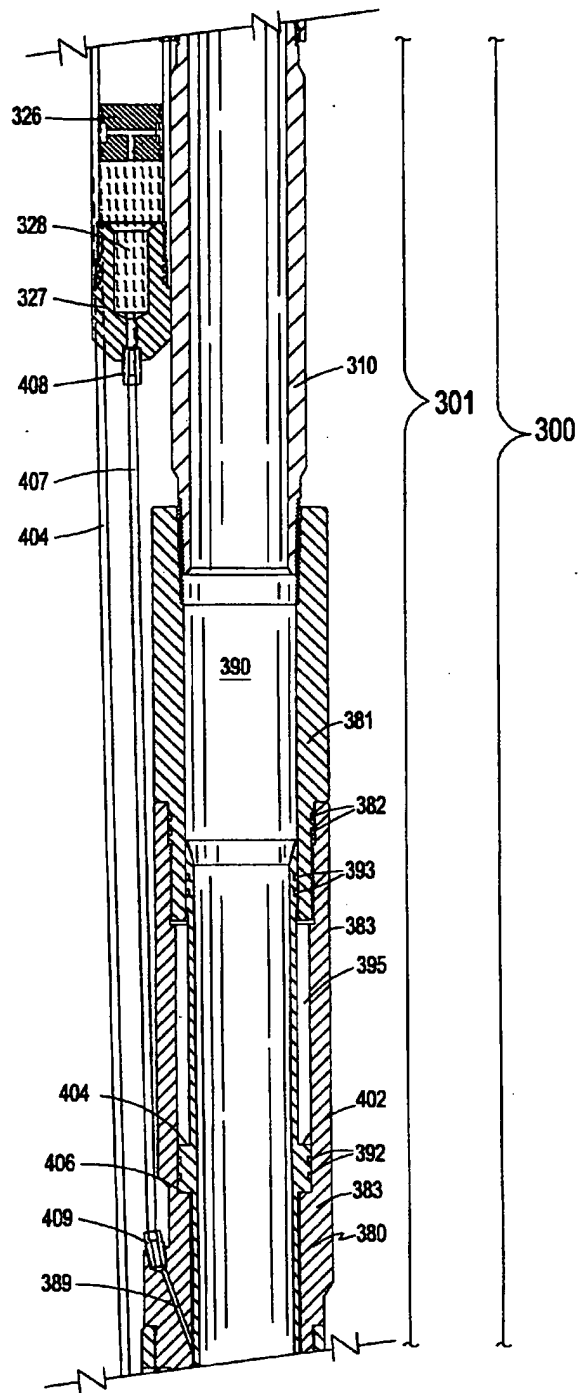
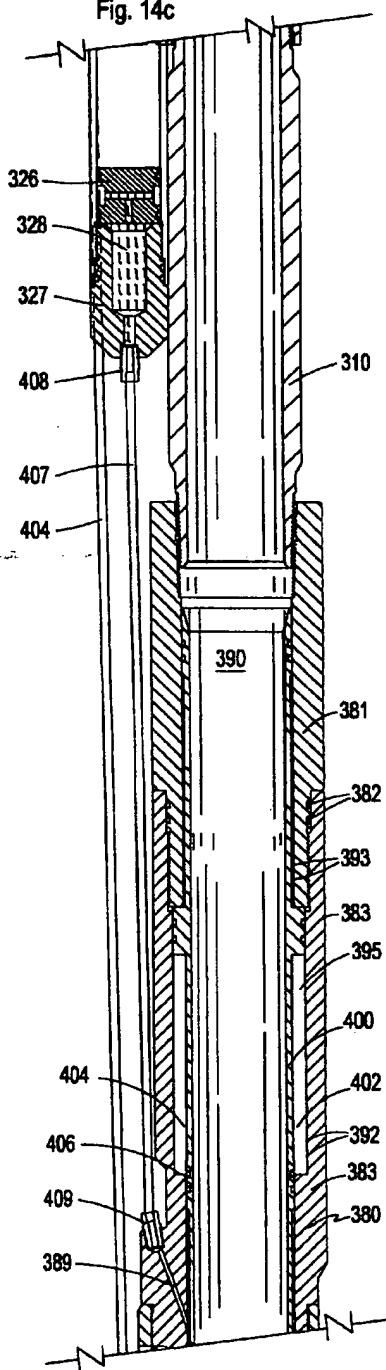


Fig. 14 a

Fig. 14c



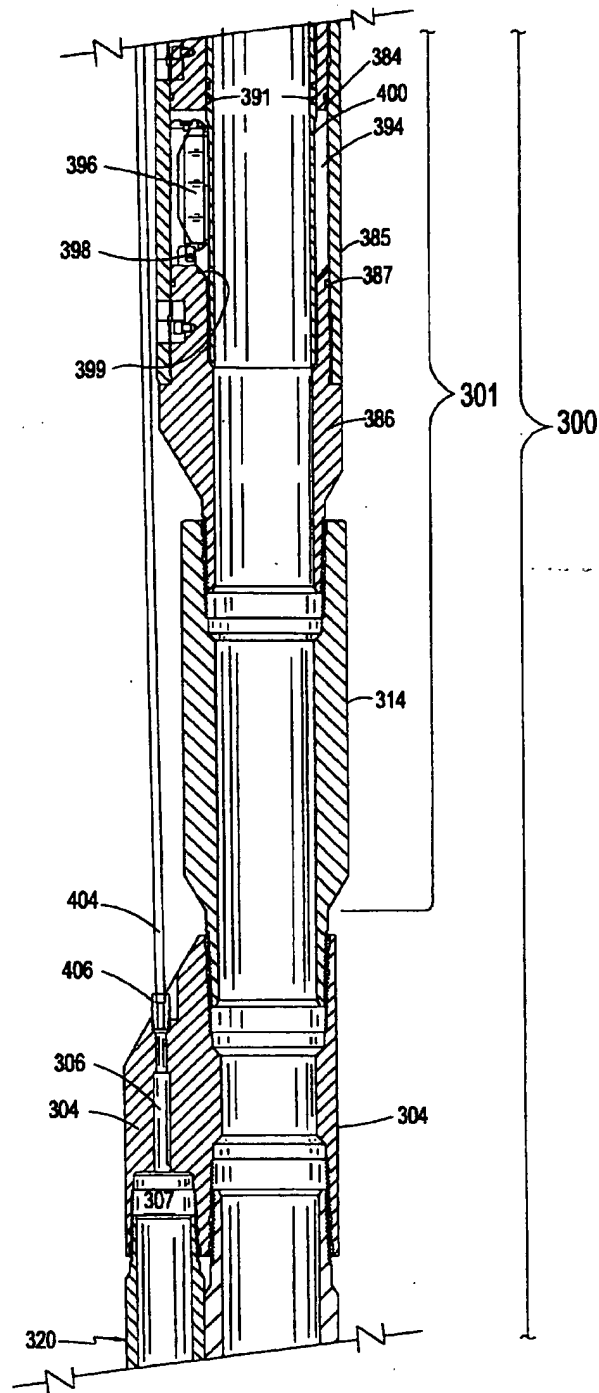
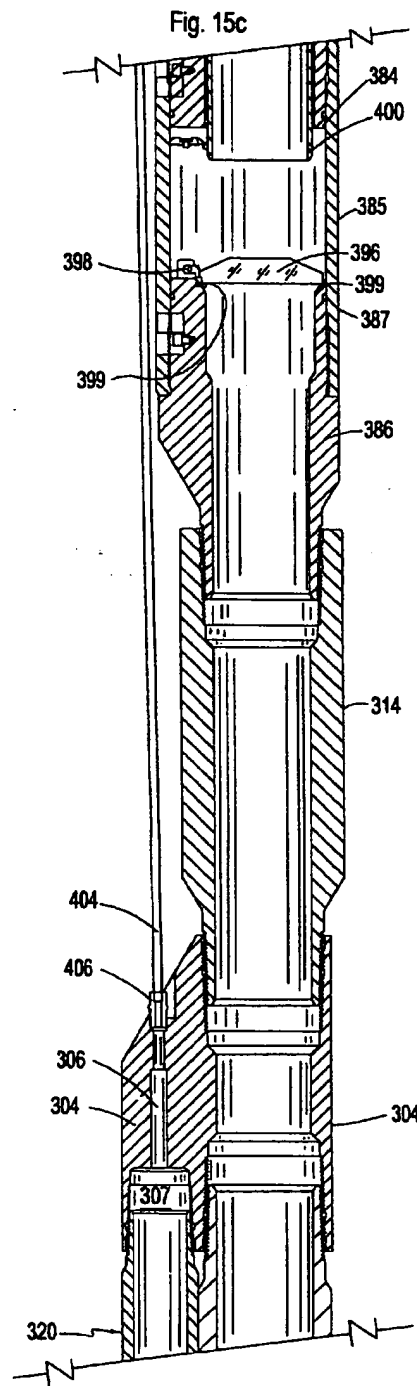
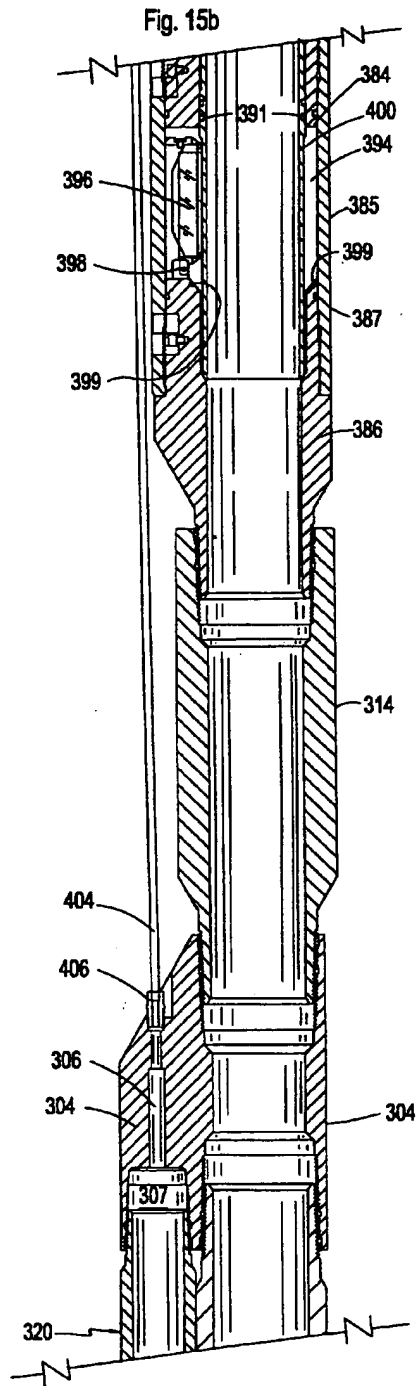


Fig. 15 a



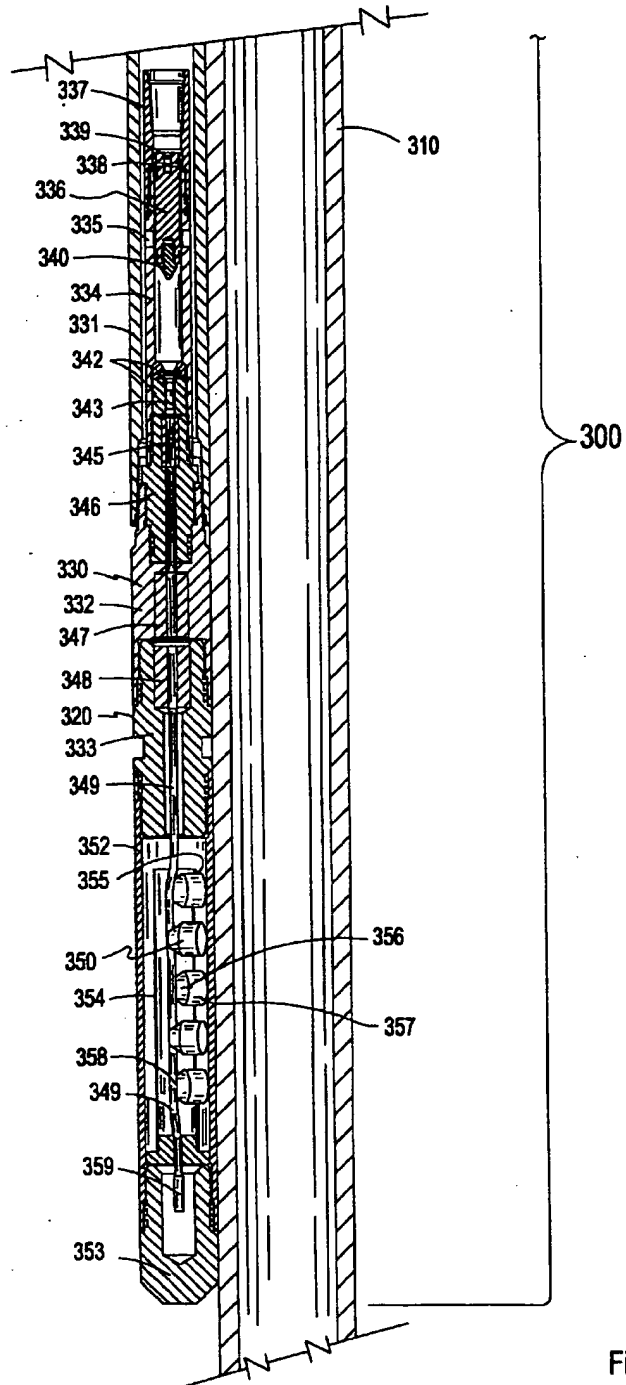


Fig. 16 a

Fig. 16b

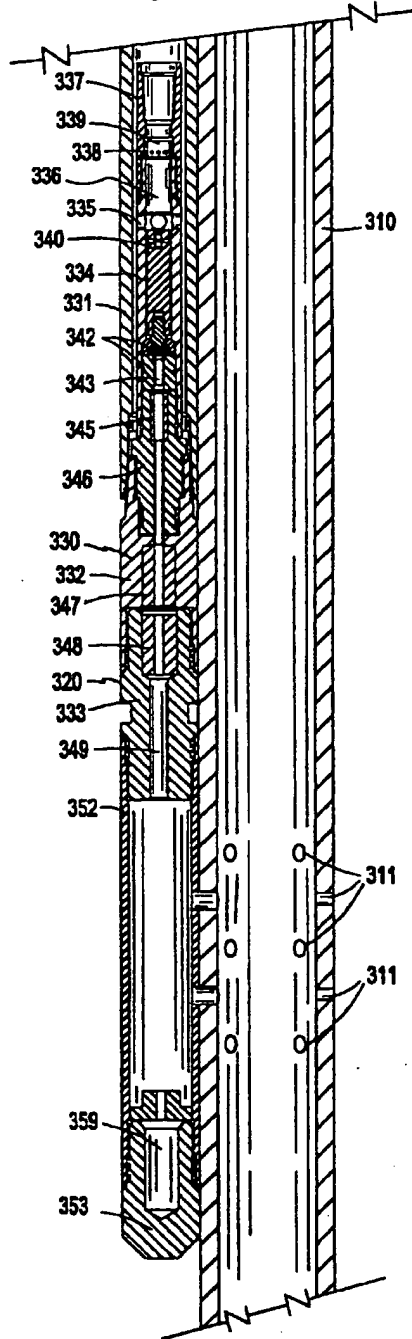
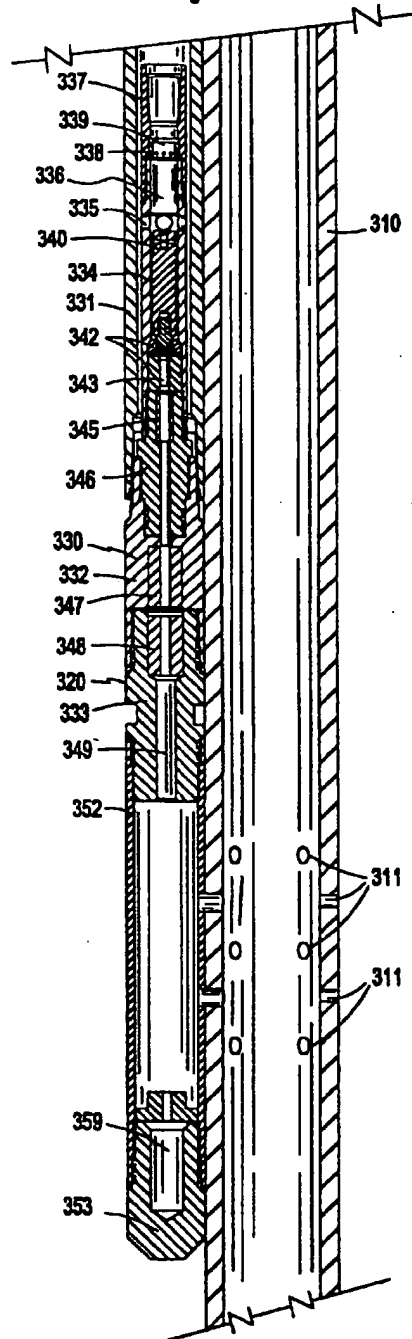


Fig. 16c



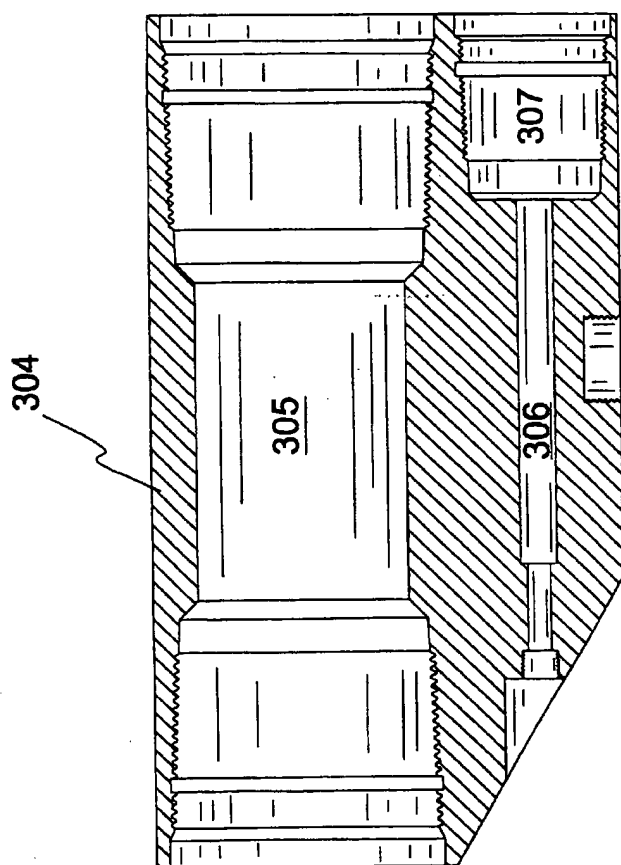


Fig. 17

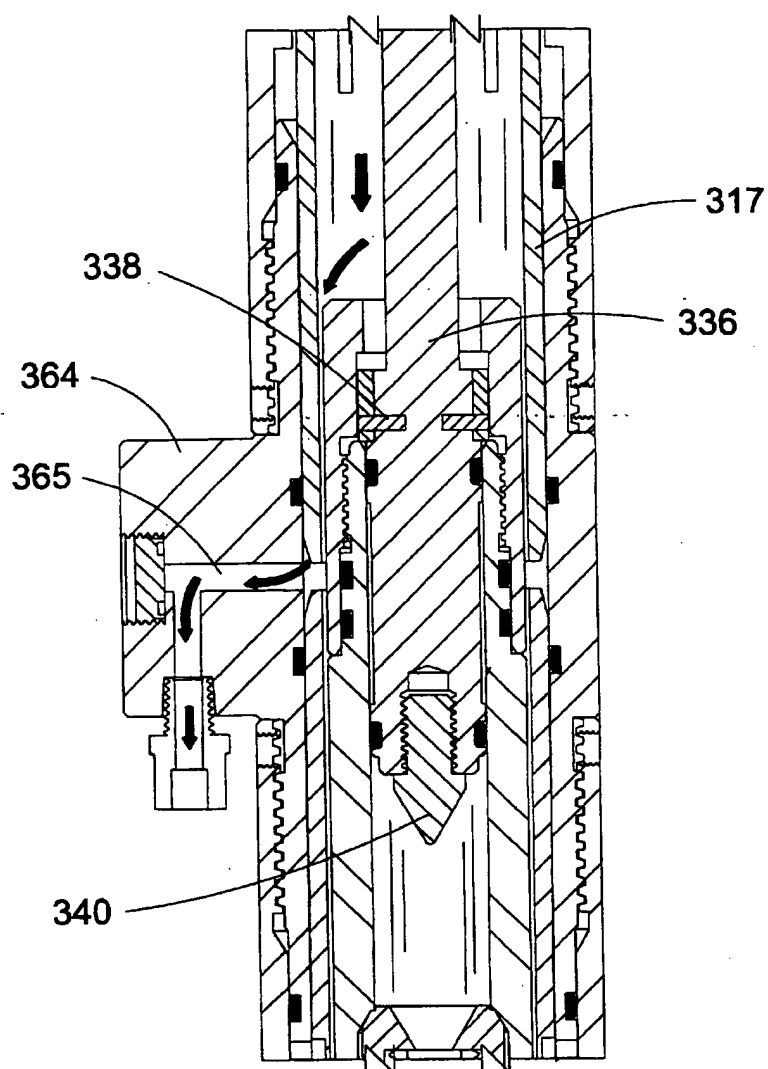


Fig. 18

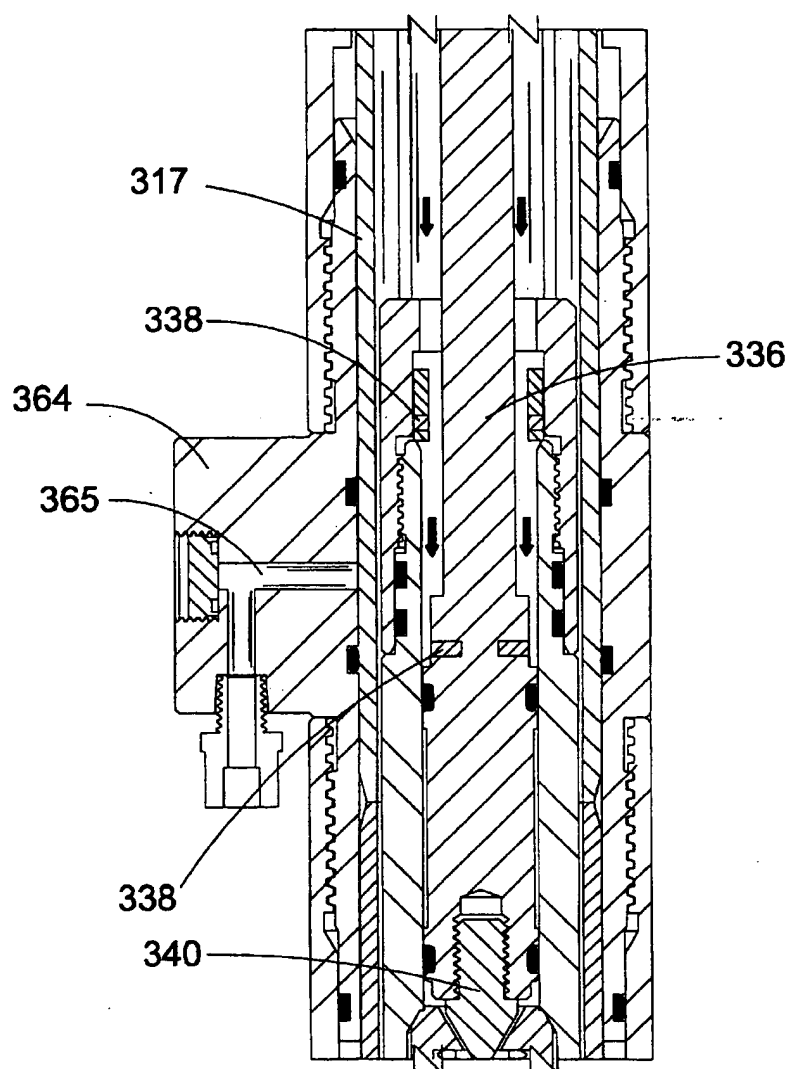


Fig. 19

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US00/05774

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : E21B 43/11
USCL : 166/55, 297

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 166/55, 55.2, 297, 298; 175/4.51, 4.52

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|------------|---|-------------------------|
| X | US 5,660,232 A (REINHARDT) 26 August 1997 (26.08.97), figures 3-6; column 3, line 60-column 4, line 24; claims 1 and 2. | 5-13, 26, 28-32, and 38 |
| Y | | 14 and 15 |
| X | Inside Circular Cutters/Outside Circular Cutters, JRC Technical Data Sheets, Jet Research Center, Inc., 1970. | 39, 42, 43, and 48 |
| Y | | 41 |
| Y | US 5,467,823 A (BABOUR et al.) 21 November 1995 (21.11.95), claims 1-4 and 15-18; figure 1; column 1, line 1-column 2, line 18. | 14, 15, and 41 |
| A | US 3,097,693 A (TERREL) 16 July 1963 (16.07.63), figures 2 and 3. | |
| A | US 3,426,849 A (BRUMBLE) 11 February 1969 (11.02.69), figures 2 and 3. | |
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| A | US 4,606,409 A (PETERSON et al.) 19 August 1986 (19.08.86), abstract. | |
| A | US 4,886,126 A (YATES) 12 December 1989 (12.12.89), abstract. | |
| A | US 5,704,426 A (RYTLEWSKI et al.) 06 January 1998 (06.01.98), abstract. | |

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

| | |
|---|--|
| * Special categories of cited documents: | "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention |
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Date of the actual completion of the international search

09 May 2000 (09.05.2000)

Name and mailing address of the ISA/US

Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Facsimile No. (703)305-3230

Date of mailing of the international search report

13 JUN 2000

Authorized officer

Jennifer Dougherty

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